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         Report from the IAB COVID-19 Network Impacts Workshop 2020
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Abstract

   The COVID-19 pandemic caused changes in Internet user behavior,
   particularly during the introduction of the initial quarantine and
   work-from-home arrangements. These behavior changes drove changes in
   Internet traffic.

   The Internet Architecture Board (IAB) held a workshop to discuss
   network impacts of the pandemic on November 9-13, 2020. The workshop
   was held to convene interested researchers, network operators,
   network management experts, and Internet technologists to share their
   experiences. The meeting was held online given the on-going travel
   and contact restrictions at that time.

Discussion Venues

   This note is to be removed before publishing as an RFC.

   Source for this draft and an issue tracker can be found at
   https://github.com/intarchboard/covid19-workshop.

Status of This Memo

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   time. It is inappropriate to use Internet-Drafts as reference
   material or to cite them other than as "work in progress."

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1. Introduction

   The Internet Architecture Board (IAB) held a workshop to discuss
   network impacts of the COVID-19 pandemic, on November 9-13, 2020.
   The workshop was held to convene interested researchers, network
   operators, network management experts, and Internet technologists to
   share their experiences. The meeting was held online given the on-
   going travel and contact restrictions at that time.

   COVID-19 has caused changes in user behavior, which in turn drove
   change to Internet traffic. These changes in user behavior appeared
   rather abruptly and were significant, in particular during the
   introduction of the initial quarantine and work-from-home
   arrangements. This caused changes to Internet traffic in terms of
   volumes, location, as well as shifts in the type of applications
   used. This shift in traffic as well as user behavior created also a
   shift in security partices as well as attack patterns that made use
   of the attack surface resulting from the shift to home-working in a
   global crisis.

   Announcement for the workshop was sent out in July 2020, requesting
   interested parties to submit position papers for the workshop program
   committee. A total of 15 position papers were received from
   altogether 33 authors. The papers are listed in Section 5. In
   addition, several other types of contributions and pointers to
   existing work were provided. A number of position papers referred to
   parallel work being published in measurement-related academic
   conferences.

   Invitations for the workshop were sent out based on the position
   papers and other expressions of interest. On the workshop conference
   calls were 45 participants, listed in Section 6.

   The workshop was held over one week hosting three sessions covering
   i) measurements and observations, ii) operational and security
   issues, and iii) future consideration and conclusions. As these
   three sessions were scheduled Monday, Wednesday, and Friday a
   positive side effect was that the time in between could be used for
   mailing list discussion and compilation of additional workshop
   material.

2. Scope

   The COVID-19 pandemic has had a tremendous impact on people's lives
   and the societies and economies around the globe. But it also had a
   big impact on networking. With large numbers of people working from
   home or otherwise depending on the network for their daily lives,
   network traffic volume has surged. Internet service providers and
   operators have reported a 20% traffic growth or more in a matter of
   weeks. Traffic at Internet Exchange Points (IXPs) is similarly on
   the rise. Most forms of network traffic have seen an increase, with
   conversational multimedia traffic growing in some cases more than
   200%. And user time spent on conferencing services has risen by an
   order of magnitude on some conferencing platforms.

   In general, the Internet has coped relatively well with this traffic
   growth. The situation is not perfect: there has also been some
   outages, video quality reduction, and other issues. Nevertheless, it
   is interesting to see how the technology, operators and service
   providers have been able to respond to large changes in traffic
   patterns.

   Understanding what actually happened with Internet traffic is of
   course interesting by its own right. How that impacted user
   experience or the intended function of the services is equally
   interesting. Measurements of and reports on Internet traffic in 2020
   are therefore valuable. But it would also be interesting to
   understand what types of network management and capacity expansion
   actions were taken in general. Anecdotal evidence points to Internet
   and service providers tracking how their services are used, and in
   many cases adjusting services to accommodate the new traffic
   patterns, from dynamic allocation of compute resources to more
   complex changes.

   The impacts of this crisis are also a potential opportunity to
   understand the impact of traffic shifts and growth more generally, or
   to prepare for future situations -- crises or otherwise – that impact
   networking. Or even allow us to adjust the technology to be even
   better suited to respond to changes.

   The scope of this workshop, based on the call for contributions,
   included:

   * measurements about traffic changes, user experience and problems,
      service performance, and other relevant aspects

   * discussion about the behind the scenes network management and
      expansion activities

   * experiences in the fields of general Internet connectivity,
      conferencing, media/entertainment, and Internet infrastructure

   * lessons learned for preparedness and operations

   * lessons learned for Internet technology and architecture

3. Workshop Topics and Discussion

3.1. Measurement-based Observations on Network Traffic Dynamics

   The workshop started with a focus on measurements. A large portion
   of the submitted papers presented and discussed measurement data and
   these submissions provided a good basis get a better understanding of
   the situation, covering different angles and aspects of network
   traffic and kind of networks.

   Changes in Internet traffic due to the COVID-19 pandemic affected
   different networks in various ways. Yet all networks observed some
   form of change, be it a reduction in traffic, an increase in traffic,
   a change in working days and weekend days patterns, or a change in
   traffic classes. Traffic volume, directionality ratios, and its
   source and destination are radically different than from before
   COVID-19.

   At a high level, while traffic from home networks increased
   significantly, the traffic in mobile networks decreased as a result
   of reduced population mobility. The observed behavior in mobile
   networks is antagonistic, yet complementary, to the one observed in
   residential ISPs. In residential networks there was a strong
   increase in video conferencing and remote learning application
   traffic due to the shift for working and learning at home. With that
   shift, the typical diurnal usage patterns in network traffic also
   changed, with peak times occuring earlier in the day and lasting
   longer over the day - reflecting the start of the work or school day
   from home. This behavior is antagonistic, yet complementary, to the
   one observed in residential ISPs.

   While diurnal congestion at interconnect point as well in certain
   last mile network was reported, mainly in March, no persitent
   congestion was observed. Further, a downward trends in download
   throughput to certain cloud regions was measured, which can probably
   explained with the increase use of cloud services. This gives
   another indication that the scalng of shared resources in the
   Internet is working reasonably well enough to handle even larger
   changes in traffic as experience during the first nearly global
   lockdown of the COVID-19 pandemic.

3.1.1. Overall Traffic Growth

   The global pandemic has significantly accelerated the growth of data
   traffic worldwide. Based on the measurement data of one ISP, three
   IXPs, a metropolitan educational network, and a mobile operator, it
   was observed at the beginning of the workshop [Feldmann2020] that
   overall the network was able to handle the situation well, despite a
   significant and sudden increase in traffic growth rate in March and
   April. That is, after the lockdown was implemented in March, a
   traffic increase of 15-20% at the ISP as well as the three IXPs was
   observed. That represents the traffic growth expected in a typical
   year which now took place in the matter of a few weeks only---a
   substantial increase. At DE-CIX Frankfurt, the world's largest
   Internet Exchange Point in terms of data throughput, the year 2020
   has seen the largest increase in peak traffic within a single year
   since the IXP was founded in 1995. Additionally, mobile traffic has
   slightly receded. In access networks, the growth rate of upstream
   traffic also exceeded the growth in downstream traffic, reflecting
   increased adoption and use of video conferencing and other remote
   work and school applications.

   Most traffic increases happened during non-traditional peak hours:
   Before the first COVID-19 lockdowns, the main time of use was in the
   evening hours during the week, whereas since March it has been spread
   more equally across the day. That is, the increase in usage has
   mainly occurred outside the previous peak usage times (e.g. during
   the day while working from home). This means that, for the first
   time, network utilization on weekdays resembled that on weekends.
   The effects of the increased traffic volume could easily be absorbed:
   either by using existing reserve capacity, or by quickly switching
   additional bandwidth. This is one reason why the Internet was able
   to cope well with the pandemic during the first lockdown period.

   Some of the lockdowns were lifted or relaxed around May 2020. As
   people were allowed to perform some of their daily habits outside of
   their home again, as expected, there was a decrease of the traffic
   observed at the IXPs and the ISP; instead mobile traffic began to
   grow again.

3.1.2. Changes in Application Use

   The composition of data traffic has changed since the beginning of
   the pandemic: the use of videoconferencing services and virtual
   private networks (VPNs) for access to company resources from the home
   environment has risen sharply. In ISP and IXP network it was
   observed [Feldmann2020] that traffic associated with web
   conferencing, video, and gaming increased largely in March 2020 as a
   result of the increasing user demand for solutions like Zoom or

Microsoft Teams. For example, the relative traffic share of many
"essential" applications like VPN and conferencing tools increased by
more than 200%.

Also, as people spent more hours at home, they tended to watch videos
or play games, thus increasing entertainment traffic demands. At the
same time, the traffic share for other traffic classes decreased
substantially, e.g., traffic related to education, social media, and
---for some periods---CDNs. In April and June, web conferencing
traffic was still high compared to the pre-pandemic scenario, while a
slight decrease in CDN and social media traffic was observed. During
these months many people were still working from home, but
restrictions had been lifted or relaxed, which likely led to an
increase in in-person social activities and a decrease in online
ones.

3.1.2.1. Example Campus Networks

Changes in traffic have been observed at University campus networks
as well, especially due to the necessary adoption of remote teaching.
The Politecnico di Torino University (Italy) deployed its in-house
solution for remote teaching, which caused the outgoing traffic to
grow by 2.5 times, driven by more than 600 daily online classes.
Incoming traffic, instead, decreased by a factor of 10 due to the
cessation of any in-person activity. Based on their measurements,
this change in traffic and network usage did however not lead to
noticeable performance impairments, nor have significantly poor
performance been observed for students in remote regions of Italy.
Outgoing traffic also increased due to other remote working
solutions, such as collaboration platforms, VPNs, and remote
desktops.

Similar changes were observed by measuring REDIMadrid [Feldmann2020],
a European educational and research network, which connects 16
independent universities and research centers in the metropolitan
region of Madrid. A drop of up to 55% in traffic volume on working
days during the pandemic was observed. Similar to findings for ISP/
IXP networks, it was observed that working days and weekend days are
becoming more similar in terms of total traffic. The hourly traffic
patterns reveal a traffic increase between 9 pm and 7 am. This could
be due to users working more frequently at unusual times, but also
potentially caused by overseas students (mainly from Latin America
and East Asia as suggested by the AS numbers from which these
connections came from) who accessed university network resources from
their home countries.

Given the fact that the users of the academic network (e.g., students and research staff) had to leave the campus as a response to lockdown measures, also the traffic in and out (i.e., ingress and egress) ratio changed drastically. Prior to the lockdown, the incoming traffic was much larger then the outgoing traffic. This changed to a more balanced ratio. This change of traffic asymmetry can be explained by the nature of remote work. On the one end, users connected to the network services mainly to access resources, hence the increase in outgoing traffic. On the other end, all external (i.e., Internet-based) resources requested during work were no longer accessed from the educational network but from the users' homes.

3.1.3. Mobile Networks and Mobility

Mobile network data usage appeared to decline following the imposition of localized lockdown measures, as these reduced typical levels of mobility and roaming.

[Lutu2020] measured the cellular network of O2 UK to evaluate how the changes in people's mobility impacted traffic patterns. By analyzing cellular network signalling information regarding users' device mobility activity, they observed a decrease of 50% in mobility (according to different mobility metrics) in the UK during the lockdown period. As they found no correlation between this reduction in mobility and the number of confirmed COVID-19 cases, only the enforced government order was effective in significantly reducing mobility and this reduction was more significant in densely populated urban areas than in rural areas. For London, specifically, it could be observed from the mobile network data that approximately 10% of the residents temporarily relocated during the lockdown.

These mobility changes had immediate implications in traffic patterns of the cellular network. The downlink data traffic volume aggregated for all bearers (including conversational voice) decreased for all UK by up to 25% during the lockdown period. This correlates with the reduction in mobility that was observed country-wide, which likely resulted in people relying more on broadband residential Internet access to run download intensive applications such as video streaming. The observed decrease in the radio cell load, with a reduction of approximately 15% across the UK after the stay-at-home order, further corroborates the drop in cellular connectivity usage.

The total uplink data traffic volume, on the other hand, experienced little changes (between -7% and +1,5%) during lockdown. This was mainly due to the increase of 4G voice traffic (i.e., VoLTE) across the UK that peaked at 150% after the lockdown compared to the national medial value before the pandemic, thus compensating for the decrease in data traffic in the uplink.

Finally, it was also observed that mobility changes have a different
impact on network usage in geodemographic area clusters. In densely
populated urban areas, a significantly higher decrease of mobile
network usage (i.e., downlink and uplink traffic volumes, radio load
and active users) was observed than in rural areas. In the case of
London, this was likely due to geodemographics of the central
districts, which include many seasonal residents (e.g., tourists),
business and commercial areas.

3.1.4. A Deeper Look at Interconnections

Traffic at points of network interconnection noticeably increased,
but most operators reacted quickly by rapidly adding additional
capacity [Feldmann2020]. The amount of increases varied, with some
networks that hosted popular applications such as video conferencing
experiencing traffic growth of several hundred to several thousand
percent. At the IXP-level, it was observed that port utilization
increased. This phenomenon is mostly explained by a higher traffic
demand from residential users.

Measurements of interconnection links at major US ISPs by CAIDA and
MIT found some evidence of diurnal congestion around the March 2020
timeframe [Clark2020], but most of this congestion disappeared in a
few weeks, which suggests that operators indeed took steps to add
capacity or otherwise mitigate the congestion.

3.1.5. Cloud Platforms

Cloud infrastructure played a key role in supporting bandwidth-
intensive video conferencing and remote learning tools to practise
social distancing during the COVID-19 pandemic. Network congestion
between cloud platforms and access networks could impact the quality
of experience of these cloud-based applications. CAIDA leveraged
web-based speed test servers to perform download and upload
throughput measurements from virtual machines in public cloud
platforms to various access ISPs in the United States [Mok2020].

The key findings included:

* Persistent congestion events were not widely observed between
   cloud platforms and these networks, particular for large-scale
   ISPs, but we could observe large diurnal download throughput
   variations in peak hours from some locations to the cloud.

* There was evidence of persistent congestion in the egress
   direction to regional ISPs serving suburban areas in the U.S.
   Their users could have suffered from poor video streaming or file
   download performance from the cloud.

* The macroscopic analysis over 3 months (June-August, 2020)
  revealed downward trends in download throughput from ISPs and
  educational networks to certain cloud regions. We believe that
  increased use of the cloud in the pandemic could be one of the
  factors that contributed to the decreased performance.

3.1.6. Last-Mile Congestion

The last mile is the centerpiece of broadband connectivity, where
poor last-mile performance generally translates to poor quality of
experience. In a recent IMC'20 research paper Fontugne et al.
investigated last-mile latency using traceroute data from RIPE Atlas
probes located in 646 ASes and looked for recurrent performance
degradation [Fontugne2020-1]. They found that in normal times Atlas
probes in only 10% ASes experience persistent last-mile congestion,
but they recorded 55% more congested ASes during the COVID-19
outbreak. This deterioration caused by stay-at-home measures is
particularly marked in networks with a very large number of users and
certain parts of the world. They found Japan to be the most impacted
country in their study looking specifically at NTT OCN, but noting
similar observations for several Japanese networks, including IIJ
(AS2497).

From mid-2020 onwards, they however observed better performance than
before the pandemic. In Japan, this was partly due to the
deployments originally planned for accommodating the Tokyo Olympics,
and more generally, it reflects the efforts of network operators to
cope with these exceptional circumstances. The pandemic has
demonstrated that its adaptive design and proficient community can
keep the Internet operational during such unprecedented events.
Also, from the numerous research and operational reports recently
published, the pandemic is apparently shaping a more resilient
Internet, as Nietzsche wrote, "What does not kill me makes me
stronger".

3.1.7. User Behaviour

The type of traffic needed by the users also changed in 2020.
Upstream traffic increased due the use of video conferences, remote
schooling, and similar applications. The NCTA and Comcast reported
that while downstream traffic grew 20%, upstream traffic grew as much
as 30% to 37% [NCTA2020] [Comcast2020]. Vodafone reported that
upstream traffic grew 100% in some markets [Vodafone2020].

Ericsson's Consumer Lab surveyed users for their usage and
experiences during the crisis. Some of the key findings in
[ConsumerlabReport2020] were:

   * 9 in 10 users increased Internet activities, and time spent
      connected increased. In addition, 1 in 5 started new online
      activities, many in the older generation felt that they were
      helped by video calling, parents felt that their children's
      education was helped, and so on.

   * Network performance was, in general, found satisfactory. 6 in 10
      were very satisfied with fixed broadband, and 3 in 4 felt that
      mobile broadband was the same or better compared to before the
      crisis. Consumers valued resilience and quality of service as the
      most important task for network operators.

   * Smartphone application usage changed, with fastest growth in apps
      related to COVID-19 tracking and information, remote working,
      e-learning, wellness, education, remote health consultation, and
      social shared experience applications. Biggest decreases were in
      travel and booking, ride hailing, location, and parking
      applications.

   Some of the behaviours are likely permanent changes
   [ConsumerlabReport2020]. The adoption of video calls and other new
   services by many consumers, such as the older generation, is likely
   going to have a long-lasting effect. Surveys in various
   organizations point to a likely long-term increase in the number of
   people interested in remote work [WorkplaceAnalytics2020]
   [McKinsey2020].

3.2. Operational Practices and Architectural Considerations

   The second and third day of the workshop were held based on more open
   discussions focussed on operational issues and the architectural
   issues arising or other conclusions that could be reached.

3.2.1. Digital Divide

   Measurements from Fastly confirmed that Internet traffic volume, in
   multiple countries, rose rapidly at the same time as COVID cases
   increased and lockdown policies came into effect. Download speeds
   also decreased, but in a much less dramatic fashion than overall
   bandwidth usage increased. School closures led to a dramatic
   increase in traffic volume in many regions, and other public policy
   announcements triggered large traffic shifts. This suggests that
   governments might usefully coordinate with operators to allow time
   for pre-emptive operational changes, in some cases.

   Measurements from the US showed that download rates correlate with
   income levels. However, download rates in the lowest income zip
   codes increased as the pandemic progressed, closing the divide with

higher income areas. One possible reason for this in the data is
decisions by some ISPs, such as Comcast and Cox, that increased
speeds for users on lower-cost certain plans and in certain areas.
This suggests that network capacity was available, and that the
correlation between income and download rates was not necessarily due
to differences in the deployed infrastructure in different regions;
although it was noted that certain access link technologies provide
more flexibility than others in this regard.

3.2.2. Applications

The web conferencing systems (e.g., Microsoft Teams, Zoom, Webex) saw
incredible growth, with overnight traffic increases of 15-20% in
response to public policy changes, such as lockdowns. This required
significant and rapid changes in infrastructure provisioning.

Major video providers (YouTube, etc.) reduced bandwidth by 25% in
some regions. It was suggested that this had a huge impact on
quality of videoconferencing systems until networks could scale to
handle full bit-rate, but other operators of some other services saw
limited impact.

Updates to popular games has a significant impact on network load.
Some discussions were reported between ISPs, CDNs, and the gaming
industry on possibly coordinating various high-bandwidth update
events, similar to what was done for entertainment/video download
speeds. There was an apparently difficult interplay between bulk
download and interactive real-time applications, potentially due to
buffer bloat and queuing delays.

It was noted that operators have experience of rapid growth of
Internet traffic. New applications with exponential growth are not
that unusual in the network, and the traffic spike due to the
lockdown was not that unprecedented for many. Many operators have
tools and mechanisms to deal with this. Ensuring that knowledge if
shared is a challenge.

Following these observations traffic prioritisation was discussed,
starting from DSCP marking, basically wondering if a minimal priority
marking scheme would have helped during the pandemic, e.g. by
allowing marking of less-than-best-effort traffic. That discussion
quickly devolved into a more general QoS and observability
discussion, and as such also touching on the effects of increased
encryption. The group was not, unsurprisingly, able to resolve the
different perspectives and interests involved in that, but the
discussion demonstrated that progress is made (and being less
heated).

3.2.3. Observability

   It is clear that there is a contrast in experience. Many operators
   reported few problems, in terms of metrics such as measured download
   bandwidth, while video conferencing applications experienced
   significant usability problems running on those networks. The
   interaction between application providers and network providers
   worked very smoothly to resolve these issues, supported by strong
   personal contacts and relationships. But it seems clear that the
   metrics used by many operators to understand their network
   performance don't fully capture the impact on certain applications,
   and there is an observability gap. Do we need more tools to figure
   out the various impacts on user experience?

   These types of applications use surprising amounts of Forward Error
   Correction (FEC). Applications hide lots of loss to ensure a good
   user experience. This makes it harder to observe problems. The
   network can be behaving poorly, but experience can be good enough.
   Resiliency measures can improve the user experience but hide severe
   problems. There may be a missing feedback loop between application
   developers and operators.

   It's clear that it's difficult for application providers and
   operators to isolate problems. Is a problem due to the local WiFi,
   the access network, cloud network, etc.? Metrics from access points
   would help, but in general lack of observability into the network as
   a whole is a real concern when it comes to debugging performance
   issues.

   Further, it's clear that it can be difficult to route problem reports
   to the person who can fix them, across multiple networks in the
   Internet. COVID-enhanced cooperation made it easier to debug
   problems; lines of communication are important.

3.2.4. Security

   The increased threats and network security impacts arising from
   COVID-19 fall into two areas: (1) the agility of malicious actors to
   spin up new campaigns using COVID-19 as a lure, and (2) the increased
   threat surface from a rapid shift towards home working.

During 2020, there was a shift to home working generally, and in the way in which people use the network, with IT departments rolling out new equipment quickly and using technologies like VPNs for the first time, while others put existing solutions under much greater load. As VPN technology became more widespread and more used, it arguably became a more valuable target; one Advanced (APT29) was successful in using recently published exploits in a range of VPN software to gain initial footholds[Kirsty2020].

Of all scams detected by the UK NCSC (United Kingdom National Cyber Security Centre) that purported to originate from UK Government, more related to COVID-19 than any other subject. There are other reports of a strong rise in phishing, fraud, and scams related to COVID [Kirsty2020]. Although, from the data seen to date, the overall levels of cyber crime have not increased, there was certainly a shift in activity – as both the NCSC and CISA (DHS Cybersecurity and Infrastructure Security Agency) saw a growing use of COVID-19 related themes by malicious cyber actors as a lure. Attackers used COVID-19 related scams and phishing emails to target: individuals, small and medium businesses, large organisations, and organisations involved in both national and international COVID-19 responses (healthcare bodies, pharmaceutical companies, academia and medical research organisations). New targets, for example organisations involved in COVID-19 vaccine development were attacked using VPN exploits, highlighting the potential consequences of vulnerable infrastructure.

It's unclear how to effectively detect and counter these attacks at scale. Approaches such as using Indicators of Compromise and crowd-sourced flagging of suspicious emails were found to be effective in the response to COVID-19-related scams[Kirsty2020], and observing DNS to detect malicious use is widespread and effective. The use of DNS over HTTPS offers privacy benefits but current deployment models can bypass these existing protective DNS measures.

It was also noted that when everyone moves to performing their job online, lack of understanding of security becomes a bigger issue. Is it reasonable to expect every user of the Internet to take password training? Or is there a fundamental problem with a technical solution? Modern advice advocates a layered approach to security defences, with user education forming just one of those layers.

Communication platforms such as Zoom are not new: many people have
used them for years, but as COVID-19 saw an increasing number of
organisations and individuals turning to these technologies, they
became an attractive target, due to increased usage. In turn, there
was an increase in malicious cyber actor activity, either hijacking
online meetings that were not secured with passwords or leveraging
unpatched software as an attack vector. How can new or existing
measures protect users from the attacks levied against the next
vulnerable service?

Overall, it may be that there were fewer security challenges than
expected arising from many people suddenly working from home.
However, the agility of attackers, the importance of robust and
scalable defence mechanisms, and some existing security problems and
challenges may have become even more obvious and acute with an
increased use of Internet-based services, particularly in a pandemic
situation and times of uncertainty, where users can be more
vulnerable to social engineering techniques and attacks.

3.2.5. Discussion

There is a concern that we're missing observability for the network
as a whole. Each application provider and operator has their own
little lens. No-one has the big-picture view of the network.

How much of a safety margin do we need? Some of the resiliency comes
from us not running the network too close to its limit. This allows
traffic to shift, and gives headroom for the network to cope. The
best effort nature of the network may help here. Techniques to run
the network closer to its limits improve performance in the usual
case, but highly optimised networks may be less robust.

Finally, it was observed that we get what we measure. There may be
an argument for operators to shift their measurement focus perhaps
away from pure capacity, to rather measure QoE or resilience. The
Internet is a critical infrastructure, and people are realising that
now. We should use this as a wake-up-call to improve resilience,
both in protocol design and operational practice, not necessarily to
optimise for absolute performance or quality of experience.

3.3. Conclusions

There is a wealth of data about the performance of the Internet
during the crisis. The main conclusion from the various measurements
is that fairly large shifts occurred. And those shifts were not
merely about changing one application for another, they actually
impacted traffic flows and directions, and caused in many cases a
significant traffic increase. Early reports also seem to indicate

that the shifts have gone relatively smoothly from the point of view
of overall consumer experience.

An important but not so visible factor that led to this was that many
people and organizations where highly motivated to ensure good
experience. A lot of collaboration happened in the background,
problems were corrected, many providers significantly increased their
capacity, and so on.

On the security front, the COVID-19 crisis showcased the agility with
which malicious actors can move in response to a shift in user
Internet usage, and the vast potential of the disruption and damage
that they can inflict. Equally, it showed the agility of defenders,
when they have access to the tools and information they need to
protect users and networks, and showcased the power of Indicators of
Compromise when defenders around the world are working together
against the same problem.

In general, the Internet also seems well suited for adapting to new
situations, at least within some bounds. The Internet is designed
for flexibility and extensibility, rather than optimized for today's
particular traffic. This makes it possible to use it for many
applications, in many deployment situations, and make changes as
needed. The generality is present in many parts of the overall
system, from basic Internet technology to browsers, from name servers
to content delivery networks and cloud platforms. When usage
changes, what is needed is often merely different services, perhaps
some re-allocation of resources, as well as consequent application
and continuation of existing security defences, but not fundamental
technology or hardware changes.

On the other hand, this is not to say that no improvements are
needed:

* Improve observability to better understand the health of the
   Internet: Going forward, the critical nature that the Internet
   plays in our lives means that the health of the Internet needs to
   receive significant attention. Understanding how well networks
   work is not just a technical matter, it is also of crucial
   importance to the people and economy of the societies using it.
   Projects and research that monitor Internet and services
   performance in a broad scale and across different networks are
   therefore important.

* Maintaining defensive mechanisms to be used in times of crisis:
   Malicious cyber actors are continually adjusting their tactics to
   take advantage of new situations, and the COVID-19 pandemic is no
   exception. Malicious actors used the high appetite for COVID-19

related information as an opportunity to deliver malware and
ransomware, and to steal user credentials. Against the landscape
of a shift to working from home and an increase in users
vulnerable to attack, and as IT departments were often overwhelmed
by rolling out new infrastructure and devices, IoC sharing was a
vital part of the response to COVID-19 related scams and attacks.

* The pandemic has shown how the effects of the digital divide can
   be amplified during a crisis. More attention is needed to ensure
   that broadband is available to all, and that Internet services
   equally serve different groups.

* We need to continue to work on all the other improvements that are
   seen as necessary anyway, such as further improvements in
   security, ability for networks and applications to collaborate
   better, etc.

* Informal collaboration between different parties needs to continue
   and be strengthened.

4. Feedback on Meeting Format

   While there are frequently virtual participants in IAB workshops, the
   IAB had no experience running workshops entirely virtually.

   Feedback on this event format was largely positive, however. It was
   particularly useful that as the three sessions were scheduled Monday,
   Wednesday, and Friday, the time in between could be used for mailing
   list discussion and compilation of additional workshop material. The
   positive feedback was likely at least partly due to the fact that
   many of the workshop participants knew one another from previous
   face-to-face events (primarily IETF meetings).

   The process for sending invitations to the workshop should be
   improved for next time, however, as a few invitations were initially
   lost, and in a virtual meeting it may be more reasonable to invite
   not just one person but all co-authors of a paper, for instance. At
   least for this workshop, we did not appear to suffer from too many
   participants, and in many cases there may be some days when a
   particular participant may not be able to attend a session.

5. Position Papers

   The following position papers were received, in alphabetical order:

   * Afxanasyev, A., Wang, L., Yeh, E., Zhang, B., and Zhang, L.:
      Identifying the Disease from the Symptoms: Lessons for Networking
      in the COVID-19 Era [Afxanasyev2020]

   * Arkko, Jari: Observations on Network User Behaviour During
      COVID-19 [Arkko2020]

   * Bronzino, F., Culley, E., Feamster, N. Liu. S., Livingood. J.,
      and Schmitt, P.: IAB COVID-19 Workshop: Interconnection Changes in
      the United States [Bronzino2020]

   * Campling, Andrew and Lazanski, Dominique: Will the Internet Still
      Be Resilient During the Next Black Swan Event? [Campling2020]

   * Cho, Kenjiro: On the COVID-19 Impact to broadband traffic in Japan
      [Cho2020]

   * Clark, D.: Measurement of congestion on ISP interconnection links
      [Clark2020]

   * Favale, T., Soro, F., Trevisan, M., Drago, I., and Mellia, M.:
      Campus traffic and e-Learning during COVID-19 pandemic
      [Favale2020]

   * Feldmann, A., Gasser, O., Lichtblau, F., Pujol, E., Poese, I.,
      Dietzel, C., Wagner, D., Wichtlhuber, M., Tapiador, J., Vallina-
      Rodriguez, N., Hohlfeld, O., and Smaragdakis, G.: A view of
      Internet Traffic Shifts at ISP and IXPs during the COVID-19
      Pandemic [Feldmann2020]

   * Fontugne, R., Shah, A., and Cho, K.: The Impact of COVID-19 on
      Last-mile Latency [Fontugne2020]

   * Gillmor, D.: Vaccines, Privacy, Software Updates, and Trust
      [Gillmor2020]

   * Gu, Y. and Li, Z. Covid 19 Impact on China ISP's Network Traffic
      Pattern and Solution Discussion [Gu2020]

   * Jennings, C. and Kozanian, P.: WebEx Scaling During Covid
      [Jennings2020]

   * Lutu, A., Perino, D., Bagnulo, M., Frias-Martinez, E., and
      Khangosstar, J.: A Characterization of the COVID-19 Pandemic
      Impact on a Mobile Network Operator Traffic [Lutu2020]

   * Mok, Ricky, and claffy, kc: Measuring the impact of COVID-19 on
      cloud network performance [Mok2020]

   * Kirsty P: IAB COVID-19 Network Impacts [Kirsty2020]

6. Workshop participants

   The following is an alphabetical list of participants in the
   workshop.

   * Jari Arkko (Ericsson/IAB)

   * Ben Campbell (Independent/IAB)

   * Andrew Campling (419 Consulting)

   * Kenjiro Cho (IIJ)

   * kc Claffy (CAIDA)

   * David Clark (MIT CSAIL)

   * Chris Dietzel (DE-CIX)

   * Idilio Drago (University of Turin)

   * Stephen Farrell (Trinity College Dublin/IAB)

   * Nick Feamster (University of Chicago)

   * Anja Feldmann (Max Planck Institute for Informatics)

   * Romain Fontugne (IIJ Research Lab)

   * Oliver Gasser (Max Planck Institute for Informatics)

   * Daniel Kahn Gillmor (ACLU)

   * Yunan Gu (Huawei)

   * Oliver Hohlfeld (Brandenburg University of Technology, BTU)

   * Jana Iyengar (Fastly)

   * Cullen Jennings (Cisco/IAB)

   * Mirja Kuhlewind (Ericsson/IAB)

   * Franziska Lichtblau (Max Planck Institute for Informatics)

   * Dominique Lazanski

   * Zhenbin Li (Huawei/IAB)

* Jason Livingood (Comcast)

* Andra Lutu (Telefonica Research)

* Vesna Manojlovic (RIPE NCC)

* R Martin EC (?)

* Matt Matthis (Google)

* Larry Masinter (Retired)

* Jared Mauch (Akamai/IAB)

* Deep Medhi (NSF)

* Marco Mellia (Politecnico di Torino)

* Ricky Mok (CAIDA)

* Karen O'Donoghue (Internet Society)

* Kirsty P (NCSC)

* Diego Perino (Telefonica Research)

* Colin Perkins (University of Glasgow/IRTF/IAB)

* Enric Pujol (Benocs)

* Anant Shah (Verizon Media Platform)

* Francesca Soro (Politecnico di Torino)

* Brian Trammell (Google)

* Gergios Tselentis (European Commission)

* Martino Trevisan

* Lan Wang (University of Memphis)

* Rob Wilton (Cisco)

* Jiankang Yao (CNNIC)

* Lixia Zhang (UCLA)

7. Program Committee

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   platform; Martino Trevisan for text on campus networks; David Clark
   on congestion measurements at interconnects; Oliver Hohlfeld for the
   text on traffic growth, changes in traffic shifts, campus networks,
   and interconnections; Andra Lutu on mobile networks; Kirsty Paine for
   text on security impacts; and thanks to Jason Livingood for his
   review and additions.

9. Informative References

   [Afxanasyev2020]
            Afxanasyev, A., Wang, L., Yeh, E., Zhang, B., and L.
            Zhang, "Identifying the Disease from the Symptoms: Lessons
            for Networking in the COVID-19 Era", https://www.iab.org/
            wp-content/IAB-uploads/2020/12/IAB-COVID-
            19-WS_102820.pdf , October 2020.

   [Arkko2020]
            Arkko, J., "Observations on Network User Behaviour During
            COVID-19", https://www.iab.org/wp-content/IAB-
            uploads/2020/10/covid19-arkko.pdf , October 2020.

   [Bronzino2020]
            Bronzino, F., Culley, E., Feamster, N., Liu, S.,
            Livingood, J., and P. Schmitt, "IAB COVID-19 Workshop:
            Interconnection Changes in the United States",
            https://www.iab.org/wp-content/IAB-uploads/2020/10/
            covid19-feamster.pdf , October 2020.

[Campling2020]
          Campling, A. and D. Lazanski, "Will the Internet Still Be
          Resilient During the Next Black Swan Event?",
          https://www.iab.org/wp-content/IAB-uploads/2020/10/
          covid19-campling.pdf , October 2020.

[Cho2020] Cho, K., "On the COVID-19 Impact to broadband traffic in
          Japan", https://www.iab.org/wp-content/IAB-
          uploads/2020/10/covid19-cho.pdf , October 2020.

[Clark2020]
          Clark, D., "Measurement of congestion on ISP
          interconnection links", https://www.iab.org/wp-content/
          IAB-uploads/2020/10/covid19-clark.pdf , October 2020.

[Comcast2020]
          Comcast, ., "COVID-19 Network Update",
          https://corporate.comcast.com/covid-19/network/may-20-2020
          , May 2020.

[ConsumerlabReport2020]
          Ericsson Consumer & IndustryLab, ., "Keeping consumers
          connected in a COVID-19 context",
          https://www.ericsson.com/en/reports-and-
          papers/consumerlab/reports/keeping-consumers-connected-
          during-the-covid-19-crisis , June 2020.

[Favale2020]
          Favale, T., Soro, F., Trevisan, M., Drago, I., and M.
          Mellia, "Campus traffic and e-Learning during COVID-19
          pandemic", https://www.iab.org/wp-content/IAB-
          uploads/2020/10/covid19-favale.pdf , October 2020.

[Feldmann2020]
          Feldmann, A., Gasser, O., Lichtblau, F., Pujol, E., Poese,
          I., Dietzel, C., Wagner, D., Wichtlhuber, M., Tapiador,
          J., N Vallina-Rodriguez, ., Hohlfeld, O., and G.
          Smaragdakis, "A view of Internet Traffic Shifts at ISP and
          IXPs during the COVID-19 Pandemic", https://www.iab.org/
          wp-content/IAB-uploads/2020/10/covid19-feldmann.pdf ,
          October 2020.

[Fontugne2020]
          Fontugne, R., Shah, A., and K. Cho, "The Impact of
          COVID-19 on Last-mile Latency", https://www.iab.org/wp-
          content/IAB-uploads/2020/10/covid19-fontugne.pdf , October
          2020.

   [Fontugne2020-1]
             Fontugne, R., Shah, A., and K. Cho, "Persistent Last-mile
             Congestion: Not so Uncommon", Proceedings of the ACM
             Internet Measurement Conference (IMC '20) , October 2020.

   [Gillmor2020]
             Gillmor, D., "Vaccines, Privacy, Software Updates, and
             Trust", https://www.iab.org/wp-content/IAB-
             uploads/2020/10/covid19-gillmor.pdf , October 2020.

   [Gu2020] Gu, Y. and Z. Li, "Covid 19 Impact on China ISP's Network
             Traffic Pattern and Solution Discussion",
             https://www.iab.org/wp-content/IAB-uploads/2020/10/
             covid19-gu.pdf , October 2020.

   [Jennings2020]
             Jennings, C. and P. Kozanian, "WebEx Scaling During
             Covid", https://www.iab.org/wp-content/IAB-
             uploads/2020/10/covid19-jennings.pdf , October 2020.

   [Kirsty2020]
             Kirsty P, ., "IAB COVID-19 Network Impacts",
             https://www.iab.org/wp-content/IAB-uploads/2020/10/
             covid19-kirstyp.pdf , October 2020.

   [Lutu2020] Lutu, A., Perino, D., Bagnulo, M., Frias-Martinez, E., and
             J. Khangosstar, "A Characterization of the COVID-19
             Pandemic Impact on a Mobile Network Operator Traffic",
             https://www.iab.org/wp-content/IAB-uploads/2020/10/
             covid19-lutu.pdf , October 2020.

   [McKinsey2020]
             Boland, B., De Smet, A., Palter, R., and A. Sanghvi,
             "Reimagining the office and work life after COVID-19", htt
             ps://www.mckinsey.com/~/media/McKinsey/Business%20Function
             s/Organization/Our%20Insights/Reimagining%20the%20office%2
             0and%20work%20life%20after%20COVID%2019/Reimagining-the-
             office-and-work-life-after-COVID-19-final.pdf , June 2020.

   [Mok2020] Mok, R. and . kc claffy, "Measuring the impact of COVID-19
             on cloud network performance", https://www.iab.org/wp-
             content/IAB-uploads/2020/10/covid19-mok.pdf , October
             2020.

   [NCTA2020] NCTA, ., "COVID-19: How Cable's Internet Networks Are
             Performing: Metrics, Trends & Observations",
             https://www.ncta.com/COVIDdashboard , 2020.

   [Vodafone2020]
              Vodafone, ., "An update on Vodafone's networks",
              https://www.vodafone.com/covid19/news/update-on-vodafone-
              networks , April 2020.

   [WorkplaceAnalytics2020]
              Lister, K., "Work-At-Home After Covid-19â\200\224Our Forecast",
              https://globalworkplaceanalytics.com/work-at-home-after-
              covid-19-our-forecast , 2020.

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