Impact case study (REF3)

Institution: University College London

Unit of Assessment: 11 - Computer Science and Informatics

Title of case study: Improving Data Transfer with Multipath Transmission Control Protocols

Period when the underpinning research was undertaken: 2010 - 13

Details of staff conducting the underpinning research from the submitting unit:

<table>
<thead>
<tr>
<th>Name(s):</th>
<th>Role(s) (e.g. job title):</th>
<th>Period(s) employed by submitting HEI:</th>
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<tbody>
<tr>
<td>Mark Handley</td>
<td>Professor of Networked Systems</td>
<td>2003 - 2020</td>
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</tbody>
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Period when the claimed impact occurred: 2013 - 2020

Is this case study continued from a case study submitted in 2014? Y

1. Summary of the impact

Research at UCL pioneered the suite of Multipath Transmission Control Protocols (MPTCP). These protocols improve the efficiency of data transfer across the Internet when compared to the classic suite of transfer protocols “TCP/IP”. The UCL team demonstrated the improved effectiveness of these protocols which has led to multiple commercial deployments, either by Internet Service Providers or by companies such as phone handset suppliers. In addition, UCL research has been incorporated into Operating Systems such as Apple’s iOS and Linux and it is now shaping the design of 5G cellular networks. As a result of UCL research, millions of users benefit every day from smoother transitions between different Internet connections ensuring that online services have a much higher performance and reliability.

2. Underpinning research

The Transmission Control Protocol, which accounts for the vast majority of all Internet traffic, allows users to transfer packets of data between two IP addresses. The TCP/IP “suite” of protocols for data transfer is fundamental to the architecture of the Internet. However, since the development of devices able to connect in multiple ways, such as phones that can transmit over Wi-Fi or cellular networks, the use of a single pathway for transmission has limited improvements in transfer speed and efficiency.

Research into Multipath Transmission Control Protocols (MPTCP) by the team at UCL has helped to address this issue. They have developed ways to transfer files between two IP addresses across multiple “subflows”. These subflows allow for a device to move between connections more smoothly or even to use multiple paths simultaneously. Previously, when a phone, for example, disconnected from a Wi-Fi network, it would not have simultaneously been using its cellular signal to transmit data; this causes an interruption to the transmission, sometimes impeding the function of apps. The same interruption could also happen when a new Wi-Fi connection was joined. Now, instead, a phone using MPTCP can transmit data using both pathways. The data transfer can now also migrate over to whichever pathway is more efficient, resulting in a better experience for the user.

Research by Professor Handley and his team at UCL was crucial to the development of these new protocols. In a 2011 paper, in collaboration with other scholars, the team at UCL demonstrated the challenges which would need to be overcome to enable MPTCP to be attached on to the existing Internet architecture (R1). This research looked at the behaviour of middleboxes (networking devices which filter or inspect data packets). By studying 142 access networks in 24 countries, they showed that issues with middlebox behaviour would interfere with data transmission in ways that would limit the extension of TCP. The measurement results in this paper guided the design of MPTCP.
The team at UCL also developed an algorithm to optimize MPTCP, preventing congestion in the transfer of data (R2). Implementing the algorithm in Linux, they were able to demonstrate the increased efficiency of MPTCP as compared to TCP. They produced further work on the principles for functioning MPTCP, taking into account the various challenges to its implementation (R3). They also demonstrated the efficiency gains of MPTCP in datacentres (R4). Because datacentres have multiple pathways to transmit within their stacks, they can transmit data using MPTCP, allowing for speedier transfer across multiple routes. By running MPTCP on Amazon’s cloud computing service, Amazon EC2, they were able to demonstrate that MPTCP outperforms TCP by a factor of three.

The results of this work were taken up by the Internet Engineering Task Force (IETF, the main standards organization for the Internet). A working group was formed to standardize MPTCP. The team at UCL authored three Request for Comments (RFCs). These are standards documents for the IETF, defining MPTCP and establishing guidelines for its use (R5, R6). These guidelines have been promoted from the experimental track at the IETF to the standardisation track. This means that individuals who are both developing products and designing deployments commercially, can use MPTCP to help shape the future of the Internet.

3. References to the research


4. Details of the impact

As a result of UCL research, its widespread dissemination (over 3,000 citations), and its uptake by the IETF, Prof Handley and team have helped to ensure a faster, smoother, more connected Internet globally. MPTCP is of growing importance to the telecoms industry and its customers. A search on Google patents for “MPTCP” currently lists 1,380 patents granted, with many more applied for. The team’s work has informed the practices of many technology companies, and improved the experiences of millions of users:
• Operating systems, such as Apple’s iOS and Linux, have incorporated MPTCP.
• The team at UCL has been involved in collaborations with service providers and 
  handset makers, such as Korean Telecom and Samsung, helping to provide faster 
  Internet.
• The research has allowed companies such as Tessares to provide more efficient Wi- 
  Fi services in rural areas.
• MPTCP is also an important feature of 5G networks, helping to improve connectivity 
  around the world.

In 2019, Mark Handley was awarded a Sigcomm award “For fundamental contributions to 
Internet multimedia, multicast, congestion control, and multi-path networks, and 
the standardization of Internet protocols in these domains” (S1). His work has had a vital impact 
on the Internet’s ongoing transformation.

Impact on Apple iOS and its users

In 2013, Apple incorporated MPTCP in iOS 7, shipping it from Linux into its own software, after 
consulting UCL research published in (R6). Their initial use case was the voice activated Siri 
assistant (S2). Siri sends audio samples from the user’s query to Apple’s servers and returns the 
answer. It is crucial that this exchange happens without delay, but an iPhone cannot know in 
advance whether its Wi-Fi link or its cellular link will work best. MPTCP allows iOS to try both. 
The phone can then rapidly migrate to the link that works best at that instant. According to 
Apple, MPTCP reduces the delay before the first word of the response by 20% and eliminates 
80% of failed connections. Based on their experience with Siri, Apple introduced Wi-Fi Assist in 
iOS 9 (released on 16 September 2015), which allowed apps such as Safari to benefit from the 
transition between subflows thanks to MPTCP. Apple enabled MPTCP for all applications on iOS 
11, meaning app designers can now make use of MPTCP to optimise their functionality. As of 
2019, Apple has incorporated MPTCP into their Apple Maps application and their streaming 
service (S2). Apple’s Networking Architect Christoph Paasch says that, as a result, users “are 
seeing much less music streaming stalls” (S2). Apple also enabled MPTCP on MacOS from 
MacOS 10.10 onwards. According to Apple, over 800 million devices run an MPTCP-capable 
version of iOS or MacOS, meaning all users of those devices now benefit from the improved 
data transfer enabled by MPTCP.

Impact of MPTCP on other telecoms services

Linux Kernel: MPTCP is now incorporated into the mainline Linux kernel (as of release 5.8, in 
August 2020), so is available for use in Android and Linux servers. Much of this work was 
performed by Intel (S3).

Korean Telecom and Samsung: In 2015, Korean Telecom (KT) teamed up with Samsung to 
launch a commercial MPTCP proxy service called Giga LTE. Giga LTE makes use of MPTCP to 
dramatically improve wireless performance. Samsung shipped an Android port of the Linux 
MPTCP implementation on Samsung S6 and S6 Edge devices sold in Korea. KT deployed proxy 
servers in their production network using the Linux MPTCP implementation. Together, these 
can be used to harness the power of Wi-Fi and phone signals at the same time. When a user selects 
“Giga LTE” on their phone, MPTCP is enabled for all applications. Connections then use both 
LTE and Wi-Fi to connect to servers on the Internet. Because of the MPTCP congestion control 
algorithm, rather than simply splitting dataflows equally between the two pathways, the Samsung 
phones can use all the available power. KT reported in 2015 that this could improve 
performance significantly. Their published results are included in the news article about Giga 
LTE (S4).

Tessares: Tessares, based in Belgium, is pursuing the proxy approach to deploying MPTCP, 
informed by the research of the UCL team (S5). Their target market is home or small business 
networks. In some areas, especially in rural locations, Internet services are delivered by ADSL at 
speeds slower than can be achieved over the faster LTE service, but LTE bandwidth may be
scarce at busy times, and is often much more expensive. By deploying MPTCP proxies in the customer's home or office router and in the telecom's network, MPTCP can preferentially use ADSL, but when high bandwidth is required and LTE capacity is available, MPTCP can use both networks simultaneously to improve performance. Proximus, Belgium's largest mobile provider, deployed Tessares MPTCP solution in 2016 in Frasnes-Lez-Anvaing, and (as of 2017) is planning a larger scale pilot (S5). A similar approach has been used by Tessares in collaboration with Croatia's Hrvatski Telecom, to bring faster Internet services to users in rural Croatia. Standards for MPTCP proxies are now being developed in the IETF (S5).

**Impact on the development of 5G**
MPTCP is now in the main 5G network system architecture specification, 3GPP TS 23.501, released in 2016 (S6). This specification, issued by the overarching standards body for telecommunications protocols, the 3GPP, governs the design and implementation of 5G around the world. The new generation of mobile data networks will use MPTCP to ensure low latency (i.e. minimal delays in the transfer of data). The 3GPP has named the technology ATSSS (Access, Traffic Steering, Switch and Splitting). ATSSS was defined in collaboration with various telecoms companies, including KT, Apple, Deutsche Telekom, Orange, and Cisco. ATSSS will allow for seamless transition between 5G and Wi-Fi, or the use of both 5G and Wi-Fi to maximise speeds. MPTCP “will play a key role in efficiently combining Wi-Fi and 5G” (S7).

KT announced on 28 August, 2019 that it had completed the world’s first “5G low latency multi-radio access technology” test in a 5G commercial network in collaboration with Tessares. According to Tessares, “ATSSS technology reduces the initial session setup time to achieve 5G ultra-low latency in a multi-radio context, resulting in a setup delay of less than half compared to previous approaches” (S8). The use of ATSSS has been described as a key “differentiator”, one of the crucial differences between 5G and previous generations of cellular networks (S8).

In addition, MPTCP informs other solutions within 5G architecture. As the IETF Network working group pointed out in 2018: "One of the key features of 5G...is dual connectivity (DC). With DC, a 5G device can be served by two different base stations. DC will play an essential role in leveraging the benefit of 5G...MPTCP could be integrated with DC and the 5G protocol stack (S7). The research into MPTCP by the UCL team has changed networking architecture and will continue to do so during the 5G rollout.

### 5. Sources to corroborate the impact (indicative maximum of 10 references)

**S1.** 2019 Sigcomm Award for Mark Handley [http://www.sigcomm.org/awards/sigcomm-awards](http://www.sigcomm.org/awards/sigcomm-awards)

**S2.** Discussions of Apple’s use of MPTCP
- A blog discussing Apple's use of MPTCP [https://www.tessares.net/apples-mptcp-story-so-far/](https://www.tessares.net/apples-mptcp-story-so-far/)

**S3.** A discussion of the Linux Kernel and MPTCP [https://www.tessares.net/a-key-step-for-mptcp-integration-in-linux-5-x/](https://www.tessares.net/a-key-step-for-mptcp-integration-in-linux-5-x/)

**S4.** Korean Telecoms and Samsung
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- A news article on the development of Giga LTE using MPTCP “KT’s GiGA LTE, World’s First Commercial Wireless 1 Giga (3-band CA + GiGA WiFi)”

S5. Tessares Press releases on their own work with proxy servers
- https://www.tessares.net/
- A discussion of Tessares work in rural Belgium

S6. 3GPP Technical Specification 23.501 (Section 4.2.10 specifies how MPTCP is used for ATSSS (Access Traffic Steering, Switching, Splitting) within the 5G network.)
https://www.3gpp.org/ftp/Specs/archive/23_series/23.501/

S7. A report by the IETF networking task force on the implications of MPTCP for 5G.
https://tools.ietf.org/id/draft-defoy-mptcp-considerations-for-5g-01.html

https://tessares.pr.co/181810-kt-tessares-successfully-test-5g-low-latency-multi-radio-access-technology-in-a-commercial-5g-network