Research Vision

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The vast majority of our day-to-day activities today depend on the Internet. We use a variety of applications—for work, education, health, entertainment, and participation in civil, political, and social life—that rely on network connectivity. Many researchers and practitioners consider the Internet and its underlying network infrastructure, consequently, as critical infrastructure [1]. Furthermore, legislative bodies of many countries have that declared access to the Internet (to a significant extent) is a human right. Efficiently, equitably, and safely using this shared infrastructure is, hence, of utmost importance today. We fail, nevertheless, on all these fronts today, because the transport protocols or algorithms (e.g., TCP, UDP, and QUIC) responsible for moving data over the network are largely deficient by design. These deficiencies are deeply rooted in the design of our networked systems, which strictly adhere to the architectural guidelines, represented as layers of abstractions, of the TCP/IP model designed for the 1970s Internet. My research focusses on designing a safe, systematic, and principled approach to rebuild these abstractions to empower innovative applications and fully exploit the capabilities of modern network infrastructure.

Why change the status quo? We create, share, and consume an astronomical volume of data over the Internet: Global Internet traffic volume grew by two orders of magnitude between 2002 and 2012, and is expected to increase by another order of magnitude by the end of 2022 [2]. Fundamental to facilitating an efficient exchange of this data between any two hosts over the Internet are the transport protocols (and the algorithms or optimizations embedded in them). They offer several key services for hosts to exchange data: (a) *in-order delivery*, which guarantees that the ordering of the sequence of bytes (constituting the data) transmitted by a sender will remain intact when delivered to the receiver; (b) *congestion control*, which promises that a sender will equitably and efficiently share the bandwidth along a network path carrying the data with other senders using that (some or all of that) path; (c) *reliable data transfer*, which ensures that the receiver receives every single byte transmitted by the sender, only once. Supporting these features over *any* end-to-end path over the Internet is hard, and two fundamental architectural limitations further exacerbate this already hard problem.

The transport protocols are largely unaware of the performance "needs" (or requirements) of applications. Different applications have, unsurprisingly, different performance (e.g., latency, bandwidth, reliability, privacy, and security) requirements. Online games typically require low bandwidth (e.g., for exchanging player positions or action updates) as well as low latency (e.g., for supporting fast-moving actions). Watching a video stream (e.g., Netflix or YouTube), in contrast, requires high bandwidth (e.g., for streaming high-resolution videos), but copes with high latency. Indeed, even a subset of the sequence of bytes transmitted by an application may have different performance requirements than the rest. There simply exists, however, no standard mechanism for applications to share such key metadata (on their time-varying performance requirements) with the transport protocols.

The "nature" (i.e., performance characteristics) of the underlying network infrastructure are largely opaque to the transport protocols. End hosts today likely have WiFi or cellular connectivity in addition to a traditional Ethernet or fiber-based wired connection. Recent developments may also bestow hosts today with options connect to satellites or microwave networks. These networks vastly differ from one another in terms of latency, bandwidth, loss, and other performance characteristics. There exists no standard mechanism for specifying their performance characteristics (or how they differ from one another) to the transport protocols. Besides, even if such mechanisms existed, the transport protocols do not know the applications' performance requirements to exploit the network in a principled manner.

Addressing these two transport protocol limitations is one of the key objectives of my research. To this end, my work aims at redesigning the network abstractions from first principles and address the following scientific challenges.

- Enable appplications to share insights into their performance requirements with the transport protocols.
- Facilitate transport protocols to learn the capabilities of the underlying network.
- Extend transport protocols to optimize the mapping between applications' requirements and the network's capabilities, and rethink the design of congestion control algorithms (CCAs) to exploit this mapping.

References

[1] G. Carle, J. Schiller, S. Uhlig, W. Willinger, and M. Wählisch. The Critical Internet Infrastructure. *Dagstuhl Reports*, 3(8), 2013.

[2] Cisco. Visual Networking Index: Forecast and Methodology, 2017–2022. https://twiki.cern.ch/twiki/pub/HEPIX/TechwatchNetwork/HtwNetworkDocuments/white-paper-c11-741490.pdf, February 2019.