Colin Hehn
September 18th, 2023
CS:3640
A2 Write-Up

The History and Conception of Internet Architecture

What design decisions went into creating the Internet as we know it today?

In the article and lecture presented, David D. Clark seeks to outline the design decisions that went into the creation of the Internet, or rather, the protocol for the Internet, otherwise known as the system we use every single day to do our jobs, talk to our family members, and watch our favorite shows. It's so integral to contemporary American society that when one's Internet goes down, a phone call to their service provider is sure to follow, with the individual feeling almost as if they've been done a disservice. Only a few would have predicted it would be this widespread, and even fewer would've had an idea of how it would be used forty years later. Despite this lack of inherent ability to tell the future, this was the problem thrust upon the architects of the Internet and its Protocol Suite back in the 1970's and 80's. To set guidelines and precedent for a completely new technology with capabilities inclusive of, but not limited to shaping the average human interaction and driving trillions of dollars worth of business. Clark speaks for all of the engineers around the world who shared the common goal of standardizing the way information is sent around the globe, as he gives us a peek into what the process looked like in not only the drafting phase of this process, but also its implementation, and its elevator pitch to the main tech stakeholders of the time.

To rewind a bit, my concept of the Internet prior to the Intro to Networking course here at The University of Iowa was rudimentary at best. A lot of the same misconceptions that I imagine exist in most members of the public sat in my brain too, alongside a solid layer of doubt often associated with approaching massively scaled, complex topics. Years upon years of some of the world's brightest minds working at the highest level went into making many of the things we enjoy today, the web included. Though the majority of the time, we are unable to get more than a peek into the thought process of some of the first folks in the cockpit. Clark remains an exception however, as his presentations, both new and old, written and spoken, offer the closest thing to a front row seat given the audience is a bit technical. In order to even basically comprehend the material he presents in his exposition on the DARPA Internet protocols, a handful of undergraduate level networking lectures is required. With the newfound knowledge of what a packet is and a rough idea of the difference between TCP and IP, among a plethora of other fundamental concepts, jumping into what the Internet would look like if it were completely redesigned today looks like a much more plausible course of action. This isn't to say that the material will all of a sudden be incredibly easy to grasp. The presentation, in particular, is spoken by a man who has led and worked in the industry his whole life, to a room containing some of the best in the computer science industry today. This meant that many of the topics covered required a second or third rewatch, at least in my case.

We'll start with the more timely, and technical, artifact of the two, "The Design Philosophy of the DARPA Internet Protocols," written by the star of today's essay, David D. Clark and published during August of 1988 in SIGCOMM, the Association for Computing Machinery's professional forum for discussing communications and computer networks. The document intends to "capture some of the early reasoning which shaped the Internet protocols" (Clark, pg. 1), as while many have written about certain implementations of network or transmission features supportive of these Internet design principles, understanding why the protocols are what they are based on such documentation is a different story altogether. The subject of focus to help convey to the reader some of that early reasoning and deliberation is the Internet Protocol Suite, TCP/IP, developed by the Defense Advanced Research Projects Agency (DARPA) back in the 1970's. At its core, the suite, which is *still* in use today by the mass majority of computers with any networking capability, was designed as an effective method for using existing interconnected networks to send multiple individual signals as one, more complex signal, a process known as multiplexing. One of its first intended use cases was for reliably connecting the ARPANET and ARPA packet radio network together, allowing users on the packet radio network to access service machines on the ARPANET, though they also wanted the protocol to have the capability to integrate connections to other networks (and transmission mediums) as well. The ARPANET was the first widespread packet-switched (grouping data into small units, called packets) computer network, completely based off of *wired* connections, whereas the ARPA packet radio network was an experiment in the idea of impromptu *wireless* data networks. This answer to connecting the two, alongside the two networks themselves, would come to be key players in the technical foundation of the globally scaled Internet, despite their original smaller-scale intentions. To put it in a more simplified form, the DARPA Internet Architecture hoped to take a signal containing some information, no matter where it came from, convert it to a universal format, send it where it needs to go, where it then could be converted to whatever form needed for processing of said information. Of course this isn't the whole story, as where it comes from does matter to an extent (sending and receiving bits via morse code may not be an accepted method of transmission), and there are many other complexities buried within the technology that powers each piece of this process, such as TCP, Transmission Control Protocol, and IP, Internet Protocol, which are some of the most prominent, and touched on heavily in Clark's exposition.

Beyond this fundamental goal of "developing an effective technique for multiplexed utilization of existing interconnected networks" (Clark, pg. 1), the American computer scientist dives into seven secondary goals that the DARPA Internet architects keyed on to produce a technology that would yield strong and successful results for years to come. The first is labeled as being of the greatest importance, with the last being of the least, and he emphasizes that the order is not arbitrary; should the list of goals be altered in any way, a completely different network architecture would result. Secondary goal number one reads: "Internet communication must continue despite loss of networks or gateways," otherwise described as "Survivability in the Face of Failure" (Clark, pg. 2). If any number of networks or gateways were to go down, and the Internet must reconfigure itself to get information from system A to system B, the systems should be able to react and continue operation without having to completely reset the state of their data exchange. This is, of course, with the assumption that the network or gateway failures don't result in a total partition of service, or the internet being divided in such a way that there is no longer a possible route from system A to system B. DARPA's hopeful solution? "Fate sharing," or taking state information about a data exchange and collecting it at the endpoint, which in this case is system B, so that this state info is only lost if system B itself is lost. This way, the overhead of keeping a stable exchange is kept to a minimum, and the two systems can react accordingly, no matter the issue happening on the Internet side of things.

The second of these goals instead focuses on keeping service availability open to many platforms and formats. The traditional "bi-directional delivery of data" (Clark, pg. 3), isn't the only process the Internet architecture would need to account for. Other processes, like XNET or digitized speech delivery, have different requirements in the field of speed, latency, and reliability, which in turn requires a complex solution, or rather, multiple complex solutions, instead of one method of transmission for all types of processes. It was this notion that separated TCP and IP, initially a single protocol. Transmission Control Protocol was originally trying to do everything by itself, and accommodate all types of Internet-based services, though many of those, including the two listed prior, didn't fit well into what TCP was trying to achieve. Thus, Internet Protocol was born to add a bit of order to the chaos outside of TCP's capabilities, and provide a basic foundation for most anything to be built on top, whereas TCP stuck to its guns, providing a reliable, sequenced data stream to the services that needed it. It was this secondary goal that spawned the User Datagram Protocol, or UDP, as well. This protocol works heavily in tandem with IP, providing an "application-level interface to the basic datagram service of Internet" (Clark, pg. 4). The hope was that by having this standardized, though low-promise, method of data transfer, most any service could be built with it, though with a level of abstraction that doesn't make assumptions about the capabilities of each individual network.

On a similar note, secondary goal number three sheds light on the necessity for the Internet architecture to support, and function, using a large variety of network archetypes. Everything from broadcast satellites, to military systems, to commercial facilities, to local area nets (LANs, such as Ethernet or ringnet), needed to be able to be integrated, and it is with this goal that Clark feels there has been great success. The reason for this success comes from the low assumptions made about each individual network, as hinted at before. These networks should be able to transmit a packet of reasonable size, at a reasonable, though not perfect, level of reliability, using some "suitable form of addressing" (Clark, pg. 5). What a reasonable measurement for both of these fields is omitted from the exposition, though I'm sure a topic for a hundred other research papers. Without an extensive list of assumed network capabilities, pressure would be created for each network to either have or imitate these capabilities, resulting in a higher entry barrier, as well as a need for re-engineering and reimplementation of each of these capabilities for every network and network interface. This approach, as Clark puts it, is felt to be "undesirable" (pg. 5).

Beyond these first three goals, the level of impact on the design of the DARPA Internet Architecture starts to fall drastically. The remaining goals cover distributed management of resources, cost effectiveness, trivial onboarding, and resource accountability. Distributed management of resources, in particular, is pointed out as "one of the most significant issues with the Internet today," due to lack of tools, "especially in the area of routing" (pg. 5), though we do have to remember this was written 30 years ago. On the other side of things, the actual distribution of these resources appeared to be going well, as Clark notes that there were many different agencies managing the Internet's gateways, even at that time. I could only assume that both of these objectives got better over time, alongside resource accountability and cost effectiveness both, which in 1988 weren't the Internet's strongest areas, again due to limited tooling for monitoring resource usage within the technology, and the nature by which many new technologies follow in terms of implementation difficulty. Clark's research paper then switches gears to dive into the *even more* technical concepts of the matter, going the most in depth to describe various intricacies of the Internet architecture, namely TCP and Datagrams. Though besides reiterating the importance of both the technologies as fundamental to the project, the details present in these sections are a hair too low-level for me to be confident they'll stick in my brain, at least this time around.

Now to move onto Clark's talk, which follows a much more contemporary tone, and describes much of the business and industry context missing from his 1988 exposition. This recap is much shorter; I find his talk more fitting of a direct reflection on the big picture rather than a trek through more minute details one by one, as was done for his article. It partly follows the story of what happened when they took the Internet infrastructure from ARPANET and worked towards bringing it to the scale we know it for today, which meant going all-in on the corporate realm. The common denominator found in many of his interactions with the top executives in the tech and Internet industry at the time, was that the protocols, methods, and techniques they were proposing catered to certain businesses. The CTO of Cisco immediately turned him down, asking: Why should they spend their time and money implementing features that would help others, he mentions Bill Gates and his own Windows, to make money? A realization occurred for Clark. The protocols they write for the Internet directly influence the business built off of it, in the form of "Industry boundaries" (Clark, 8:30). Should the protocol have been written to include details in the network layer that would otherwise be covered by the application layer, for instance, companies like ISP's would most likely be forced to operate in a completely different way. An awesome quote (besides the Cisco exec one) that I have to include is the one from Clark's economist friend, who happened to work at Google, saying "The Internet is about routing money; routing packets is a side effect, and you screwed up the money routing protocols!" (9:15). It turns out that no matter how complex, technical, or computer science focused the Internet was, or maybe another groundbreaking technology in the future may be, chances are that other disciplines, especially those most concerned with how people and businesses operate, will take the focus! It seems most of the folks not completely enamored with the surreal engineering of the Internet and its protocol were quick to wonder what the brass tacks of the matter were. Are these proposed features going to help them increase revenue, or help others do so at their expense?

The computer scientist proceeds to elaborate on a few of the other pieces of the Internet protocol that they didn't quite figure out as well as they may have wanted, which are also featured in his book, *Designing an Internet,* published in 2018 through the MIT Press. The two most notable known flaws in the designed architecture were network management and security. The first is most concerned with protocol longevity; and the lack of network management tooling created is homage to two conflicting theories, one, that maximum longevity can be achieved through *constant adaptation* as requirements for the technology change. The other, is that *stability* is key, offering a "platform layer" for innovators in the space to build off of. Once they build off of the platform, they need it to operate just as expected, in order for their own services to operate as expected. The result, like most things, was a vastly more mature Internet (in protocol, features, revisions), and a relative balance of the two technical ideologies, much like his chosen analogy, the carburetor of the automobile industry. The flaw of security in the written Internet protocol, on the other hand, was a result of little network and information security knowledge circulating at the time (naturally). The only organization for them to turn to at the time was the US's National Security Agency, who in turn told them to completely direct their focus to disclosure control. The brilliant solution on that front was, if there is some sort of data leak, turn the network off. It was apparent that their heads were not in the right place as it concerned the future of the Internet Clark was working hard to create, as at the time it didn't really concern their line of work. Beyond disclosure control, or confidentiality, the remaining elements of the big three in information security (integrity, and availability), spiral into many hypotheticals; all of which lead back to one simpler concept. Making the Internet insecure by design, a continuance down the path of low-assumption protocol creation, just as the Internet architects intended.

How would the Internet look, were it to be designed today? How did the Internet look, when it was first created? How will the Internet look, twenty years from now? Clark attempts to shed some light on these questions, in both a technical and narrative manner with his presentations, one created thirty years after the other. The Internet is now a household name (to put it lightly), and after soaking in the author's insight, it's easy to see how its profound impact on the way people, businesses, and governments run on a daily basis would be vastly different should even a single clause have changed in the hyperattentive work of the DARPA team and those who succeeded them one, ten, or even twenty years later.