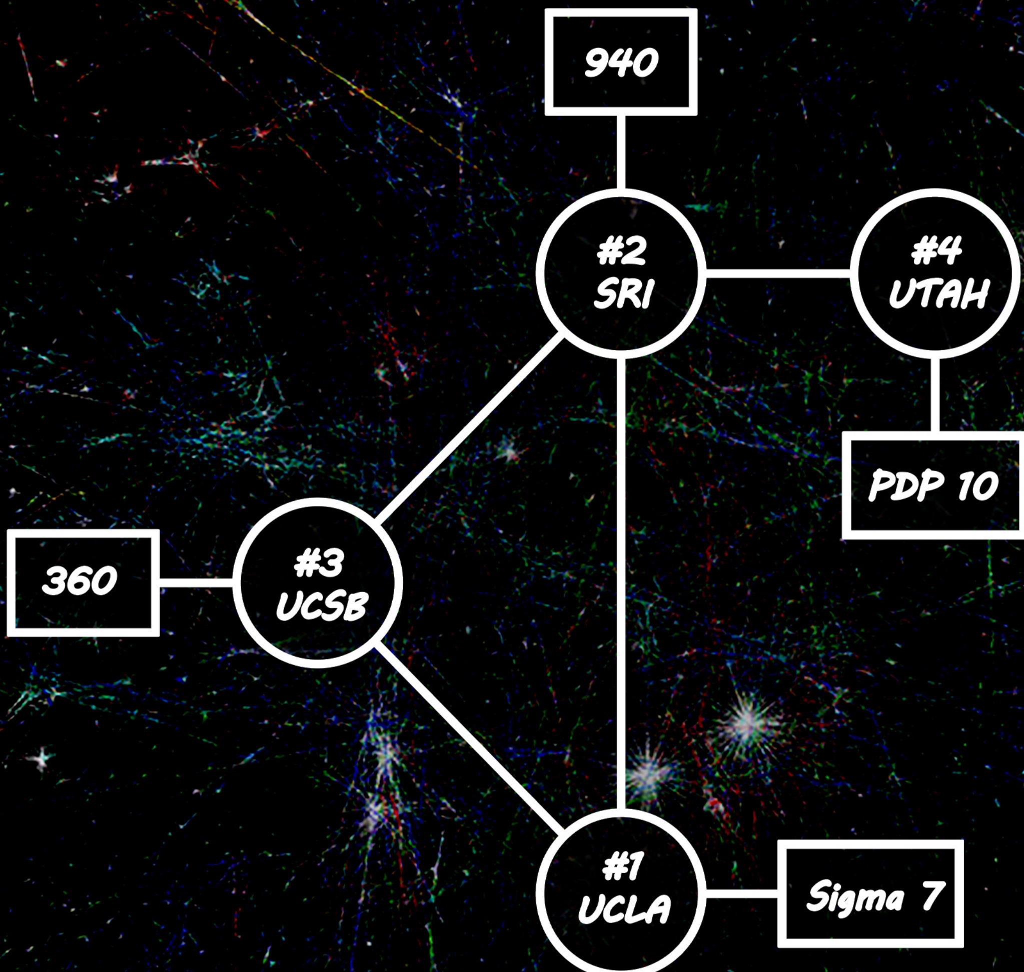
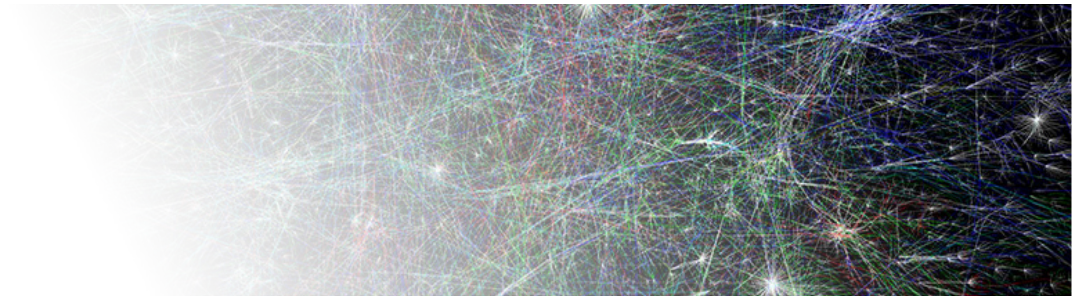
DARPA

ARPANET



Advancing National Security Through Fundamental Research

ARPANET



THE NEED AND OPPORTUNITY

DARPA research played a central role in launching the information revolution, including furthering much of the conceptual basis for today's internet – a ubiquitous, global network for sharing digital resources among geographically separated computers. The world-changeing consequences of the research continue to unfold on a daily basis.

The roots of the modern internet lie in the groundbreaking work DARPA began in the 1960s under program manager Joseph Carl Robnett Licklider to create what became the ARPANET. At the time, the agency was known as the Advanced Research Projects Agency, or ARPA. In its earliest form, the ARPANET began with four computer nodes, and the first computer-to-computer signal on this nascent network was sent between UCLA and the Stanford Research Institute on Oct. 29, 1969.

Secure communications and information-sharing between geographically dispersed research facilities were among the ARPANET's original goals. As more computers became involved in this early computer network, however, engineering problems arose. A key issue was maintaining communications, because if the ARPANET behaved like a traditional circuit-based telephone system, failure of a single node could take down the entire network.

What was needed was a means to get messages to their destination in a way that did not depend on any single node. This is the challenge that spawned the concept of packet switching. By moving packets of data that dynamically worked their way through a network to the destination where they would reassemble themselves, it became possible to avoid losing data even if one or more nodes went down. A common communications protocol between computers was also necessary, because the computers involved were not always compatible. Building a protocol and the software that would allow different computers to communicate and "internetwork" was a significant challenge.

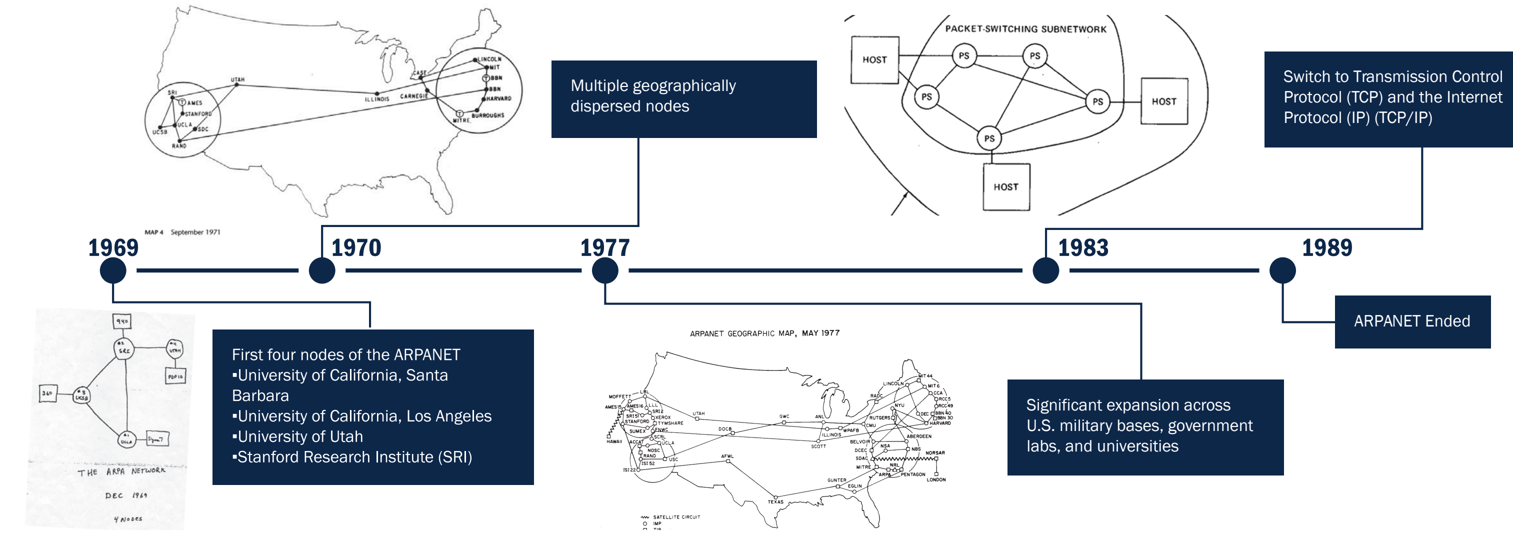
THE DARPA SOLUTION

The ARPANET was established in the last months of the 1960s, but the first major demonstration of its networking capabilities took place in Washington D.C., in 1972. At this time, the Department of Defense (DoD) became interested in using computers for command and control. Unlike the ARPANET, which used dedicated phone lines to connect computer facilities together, the military wanted a mobile network to link tanks, planes, ships, and other assets together. That capability required the use of radio and satellite systems.

By 1973, DARPA-supported researchers had come up with four different packet-switching technologies, which led to the next challenge: to develop standards that would enable these separate communications technologies to, in turn, communicate with each other. Dr. Vint Cerf, who was at Stanford University at the time and working on contract for DARPA, recalls that it took about six months of work to develop the right system architecture and create a rough protocol for controlling and managing the packet traffic.He and Robert Kahn, then

One of the many essential steps in the creation of what would become known as the internet occurred in 1968 when ARPA contracted BBN Technologies to build the first routers, known as Interface Message Processors or IMPs, which enabled ARPANET to become operational the following year. (Photo courtesy of Steve Jurvetson under a CC BY 2.0 license)

THE EVOLUTION OF ARPANET



The foundation of the current internet started taking shape in 1969 with the activation of the four-node network, known as ARPANET, and matured over two decades until ARPANET was deactivated as it became subsumed by the much more extensive network of networks, that is, the internet.

the director of DARPA's Information Processing Techniques Office (IPTO) and who in 1976 hired Cerf as a program manager, began work on what would become the Transmission Control Protocol (TCP) and the Internet Protocol (IP).

The initial implementation of the first TCP/IP protocol occurred at Stanford in 1975. As testing progressed the next few years, the now-famous protocol was being implemented on an exponentially growing number of computer systems around the world. In January 1983, enough individual networks had networked with each other that the ARPANET had evolved into the internet, although the original ARPANET itself was not formally decommissioned until 1990.

By the early 1980s, the bones of what would become the internet were in place. This new and growing network, with continued support by DARPA and DoD, became available to the academic community, which led to the launch of other government networks. Prominent among these was NSFnet, which the National Science Foundation established in 1985 to further the causes of advanced research and education.

In 1988, Cerf, who was then vice president of the Corporation for National Research Initiatives, received permission from the Federal Networking Council to connect the MCI Mail service, which had been providing commercial email services over phone lines via modem since 1983, to the computer-based internet. As president of MCI's Digital Information Services from 1982 to 1986, Cerf had led the development of MCI Mail. This authorization served to break the restriction prohibiting commercial electronic communications from traveling over the government backbone. With service beginning in 1989, this new commercial, rather than government-based, email service opened the floodgates for other commercial players. The major email providers of the time (including AOL, CompuServe, and Telenet's Telemail), which were providing messaging via telephone modems, followed MCI Mail's lead and shifted their traffic to the emerging internet. This rapid expansion of commercial internet services prompted the NSF to shut down its dedicated backbone in 1995.

In the mid-1990s, DARPA sought to build on this rapid technology development and deployment by delivering internet applications that would make possible secure, dependable battlefield communications. The key issue was that unlike the civilian internet, a military network could not depend on fixed infrastructure such as cell towers, routers, and server farms, partly because these fixed nodes would be prime and easy targets on a battlefield and partly because such infrastructure probably would not be available where and when it was needed.

What was needed was a mobile network. Toward that end, DARPA-backed research helped create a network of devices, including laptop computers and mobile phones, which did not require a fixed infrastructure. Instead, each mobile device could send and receive information from one another. Should one device be lost to the network, many others would still be available to send and receive data. Scaled upward from a local area network, the concept paved the way for "mesh networks."

THE IMPACT

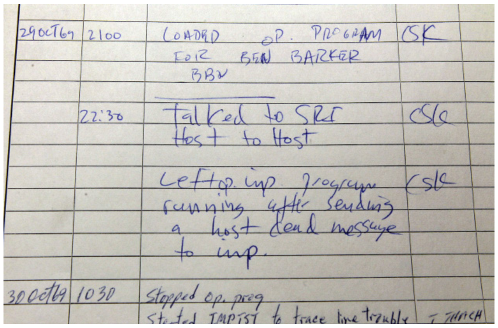
In military contexts, mesh networks undergirded the implementation of a series of operational communications systems, among them Common Data Link (CDL), the Tactical Common Data Link (TCDL), and Tactical Targeting Network Technology (TTNT).

For the civilian world, mesh networks would mean investing less in expensive and vulnerable infrastructure, and instead in building networks that were cheaper and more robust. Perhaps more importantly, such networks could deliver the internet to large swaths of the world that still lacked access. An increasingly consequential benefit of mesh networks is that they enable various devices on the Internet of Things (IoT) – things like thermostats, home automation systems, vehicles, and wearable devices – to communicate with each other as well as provide connectivity for more devices that might be too far away from an internet service provider.

In figures cited by the Congressional Research Service, the number of IoT devices in 2019 is likely to grow from the nearly 10 billion that were active in 2019 to more than 21 billion by 2025. This explosion of devices creates both great benefits and great challenges. The IoT depends upon making the data of those connecting devices accessible to IoT companies and storable in the cloud. This raises issues of privacy and security, as well as of citizens' ownership and control of their own data.

LOOKING AHEAD

Today, DARPA's internet-related research addresses concerns regarding autonomy, security, and privacy. The DARPA program Brandeis, for example, centers on breaking the tension between maintaining privacy and being able to tap into the huge value of data. Rather than having to balance between them, Brandeis aims to enable safe and predictable sharing of data in which privacy is preserved. Programs such as Explainable AI seek to develop automated tools that explain how artificial intelligence systems arrive at conclusions and make decisions. A goal here is to develop foundations of trust in AI as it becomes more prevalent. Another program, Media Forensics (MediFor), is investigating the capability to automatically detect manipulations of online imagery and to reveal precisely how these manipulations were performed.



This historic log entry for the Interface Message Processor (IMP) at UCLA records the first ARPANET message on 10/29/1969, at 22:30 Pacific Time, from Boelter Hall 3420. On the cover page of this vignette is a "back-of-the-napkin" sketch (from December 1969) of the nascent ARPANET and its four original nodes.

Though the internet's increasing ubiquity brings a mix of promise and peril, today it has in many ways fulfilled Licklider's vision of "the main and essential medium of informational interaction for governments, institutions, corporations, and individuals." He sent that forward-looking vision to his colleagues nearly sixty years ago in a now famous memo to the ARPA research community on April 25, 1963. This year, according to the technology firm Cisco, some 5.3 exabytes (10^{18} bytes) of data traffic will course the internet each day, a rate equivalent to transmitting every movie ever made every two minutes.