Musings on change: driver for SDN

Timothy A. Gonsalves

CSI Transactions on ICT

ISSN 2277-9078

CSIT
DOI 10.1007/s40012-020-00268-6

ONLINE FIRST

Springer

CSIT
https://doi.org/10.1007/s40012-020-00268-6

SPECIAL ISSUE ON SDN

Musings on change: driver for SDN

Timothy A. Gonsalves[1]

Abstract In this talk, we examine change and the rate of change from antiquity to the present, and we extrapolate to the future. We draw on the measures of social development due to historian Ian Morris. This shows that we are in an age of exponentially-increasing rate of change that will only increase unpredictably in the future. This necessitates a flexible architecture for the Internet to handle the future. We motivate the needs by the FarmerZone project, a futuristic application of AI to precision agriculture in India. Software-defined networks (SDN) is a promising alternative to the inflexible hardware routers of today's Internet. We discuss some of the challenges of SDN. One is rollout of SDN routers without disrupting the Internet. Another is scalability of the control plane of SDN. As SDN tends to be multi-vendor, ensuring security is a particularly difficult challenge. Rapid mobility with wireless networks is another issue.

Keywords SDN · Disruptive change · Precision agriculture · Internet · Network security · Scalability

1 Introduction

The rate of change in technologies and societies is increasing. In this talk, we look at the disruptive changes that we see in the world today and, to give a historical perspective, in the past. These are extrapolated to the future. We will see what the implications of these changes are for the Internet and for SDN. This is motivated by the needs of a real applications, viz. precision agriculture in India.

✉ Timothy A. Gonsalves
tag@iitmandi.ac.in

1 IIT Mandi, Kamand, Himachal Pradesh, India

2 Disruptive changes

We have experienced various disruptive changes recently. WhatsApp was introduced in 2009. Within 5–6 years, it was being used globally and it has transformed the way in which people communicate and share information, such as, making use of WhatsApp groups. A little before that was Facebook in 2004. Within about 10 years, almost everyone in countries around the world have Facebook accounts and are using Facebook. Facebook is also a disruptive technology as it has completely changed the way societies work and live. Facebook has even changed how we are governed: it has influenced recent elections. Facebook and WhatsApp are based on the Internet which started around 1969. It took about 30 years before the Internet became a global phenomenon and was used for commerce, education and other such activities.

Going further back, the telephone was invented in 1876 and it took about 120 years before the telephone became widespread. Gutenberg invented the printing press in 1440 and it took about 300 years for it to spread through the world. Until the invention of the printing press, all books were handwritten. The printing press again transformed society. Instead of having primarily monks and priests writing books and controlling knowledge, anyone who had a little money could print a book. Knowledge was no longer controlled by the religious. Knowledge got democratized and disseminated widely, leading to the flowering of science and technology.

Going even further back, when human societies first evolved, they were nomadic tribes of hunter–gatherers.

Agriculture started around 11,000 BC in the Mesopotamia area of the Middle East and slowly spread over the world. It took about 6000 years for agriculture to spread everywhere. Instead of being nomadic, people settled down in villages, cities and towns and built up empires and nations. Thus, agriculture was a disruptive technology.

These disruptive changes are summarized in Table 1. For new technologies to become global and disrupt societies around the world, over the past few centuries, they have been taking less and less time. The rate of change is inversely proportional to the time it takes for the technology to go global. From agriculture to printing to WhatsApp, *the rate of change increased slowly at first and now it is increasing exponentially* (Fig. 1).

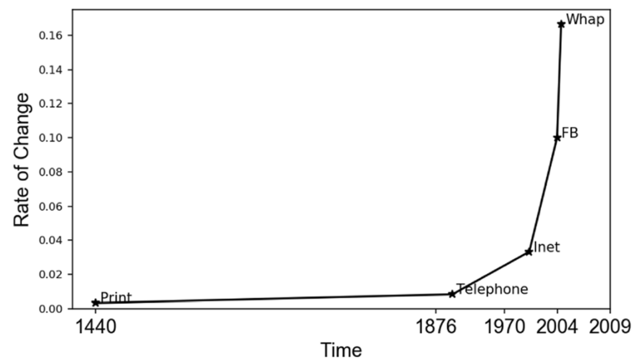


Fig. 1 Rate of change over recent 600 years

2.1 Historical perspective

Let us look at a more systematic study of the rate of change. Ian Morris, Professor of History, Classics and Archaeology at Stanford University has done a study of the development of societies from ancient times up to the current time [1]. Unlike many historians who take a qualitative view of development, he proposed a quantitative measure of development. In order to measure the development of a society, you need to have some metrics. He followed Einstein's principle, that is, when trying to measure or understand something, keep it simple. When you look at a society, there are 1000 s of parameters that describe the society such as the population, the nature of the people, the climatic conditions and so on. Out of these, Morris has chosen only 4 orthogonal parameters to describe the society, i.e. *energy capture, social organization, information technology and war making capacity*.

The first parameter is *energy capture*, that is, the way that the society uses energy. For example, in the early stages of agricultural societies everyone contributed manual labour to the agriculture. As time went by, they started using animal power. Once animals started to be used to plough the fields, a smaller number of people were required for ploughing and some people were now free to do other things. So, people could take on other non-agricultural occupations. They could become bureaucrats who collect taxes, people who design the infrastructure, build the water systems and the healthcare systems, and so on. This energy capture increases as societies start using fossil fuels, solar power, nuclear power and other sources of energy. Estimates of GDP as a function of energy show that an increase in energy causes an increase in GDP.

Table 1 Timelines of a few disruptive technologies

Technology	Introduced	Global (years)
Agriculture	∼ 11,000 BC	∼ 6000
Printing	1440 AD	∼ 300
Telephone	1876 AD	120
Internet	1970 AD	30
Facebook	2004 AD	10
WhatsApp	2009 AD	6

The second measure of the development of a society is the *ability to organize*. This is important because the ability to organize well implies that it is possible to have larger cities. A city requires a lot of organization. The city needs to have water supply, food supply, services, law and order, sewage treatment and disposal, garbage disposal and so on. If all of these are available and people live in cities, there would be tremendous power. That is, if some goods or services are needed, it is easier and cheaper to get these from someone else in the city, than is the case in a village. So, social organization is important for societies to develop.

The third measure is *information technology*. This is not information technology in the sense of computers that we use today. Information technology is collecting and processing data, not necessarily by computers but often by human beings. This measure is also important because if we consider a social organization such as a big city, taxes are to be collected. In order to collect taxes, it is necessary to know what different people are producing. Bureaucrats collect this information, figure out the taxes, collect the taxes and keep track of the revenue and expenditure and so on. All of these require the ability to process information. As the society gets better and better at collecting and processing information, its development will increase.

The final measure is the *ability to make war*. This measure is important because a society requires many resources, such as human resources, land, energy, raw materials and so on. If a society is better at fighting, it can capture more of its needs, else, it will lose resources to marauders. Thus, war-making capacity is also an important measure of the development of a society. Even today, it can be seen that the nations that are considered to be developed and powerful also happen to be the ones that have the deadliest war machines.

2.2 Future perspective

Using his 4 measures of societal development, Morris estimated the values of these measures starting from 14,000 BC up to the present. According to his measures, in 14,000 BC, the development index of the leading society was about 6. By 2000 AD, the development of the leading society had gone up to around 1000. There is an almost linear growth from 14,000 BC up to about 1000 AD, and in the last few hundred years the trend is towards an exponential growth. The systematic analysis done by Morris shows a similar trend to the anecdotal evidence that we mentioned in the introduction. This seems to indicate that not only is technology changing rapidly, but societies themselves are also changing very rapidly. Morris has predicted development in the future by extrapolating past trends. In 2000 AD, the development index was around 1000, in 2050, it will be around 4000 and in 2100, it goes up to nearly 10,000.

The message from this is that during the last 16,000 years as human societies evolved from cave paintings to Facebook and Instagram, the development index rose from 6 to 1000. In the next 100 years, we are going to see 10 times as much change compared to the last 16,000 years. Can we comprehend such enormous change? Today, even people who do not understand technology at all can upload a photo, which could be seen by anyone in the world within seconds. In the future, it is quite likely that the moment you have a thought, everyone in the world knows your thought within milliseconds! This may sound like science fiction, but it can happen with the kind of technology we have today in rudimentary forms for sensing brain waves and for injecting signals into the brain. This technology will mature by leaps and bounds in the next 20 to 30 years and become commonplace. *The changes during the coming decades are going to be unimaginable.*

3 An application: precision agriculture

To highlight the future demands on the Internet, we touch on one application. Agriculture is very important in India and worldwide. After transforming nomadic societies into settled ones, agriculture evolved very slowly for millennia. For centuries, farmers have relied on traditional knowledge. Today, this reliance on traditional knowledge is not good enough. Because of globalization, the markets are no longer the familiar local ones. The other reason is the effect of climate change. The traditional knowledge of weather patterns, especially the monsoon, is no longer good enough, because weather patterns change unpredictably from year to year due to climate change.

How does the farmer handle this? One way is using Internet of things (IoT) and artificial intelligence (AI). There are a large number of sensors which can collect a lot of data like the soil conditions, weather, moisture and so on. In addition, details on seeds used, market prices, cost of transportation, cost of cold storage, data about the yield can also be collected. Data from millions of farms can be collected. All these are fed into the database and machine learning is used to identify patterns and give advisories to farmers which are very specific to their locality based on the temperature, rainfall and other factors. Similarly, for different farms, different advisories are given. This will help farmers to cope with both globalization as well as climate change. This is the idea of what is called *precision agriculture*.

These ideas are being implemented in the *FarmerZone*™ project funded by the Department of Biotechnology (DBT) and led by IIT Mandi. Its goal is to provide AI-based advisories to small and medium farmers (Fig. 2) [2]. Agriculture-related data is collected from a variety of sources. This includes weather conditions, soil conditions, information about seed varieties, pesticides and fertilisers, market prices, etc. The data is stored in a cloud repository. This is used to generate farm-specific advisories on crop management, marketing, etc.

Currently, *FarmerZone* caters to potato farmers in Punjab, UP and Himachal Pradesh in North India. In the future, *FarmerZone* will expand to serve the whole of India, with over a 100 million farmers and over 20 major crops. So, the amount of data that needs to be collected and

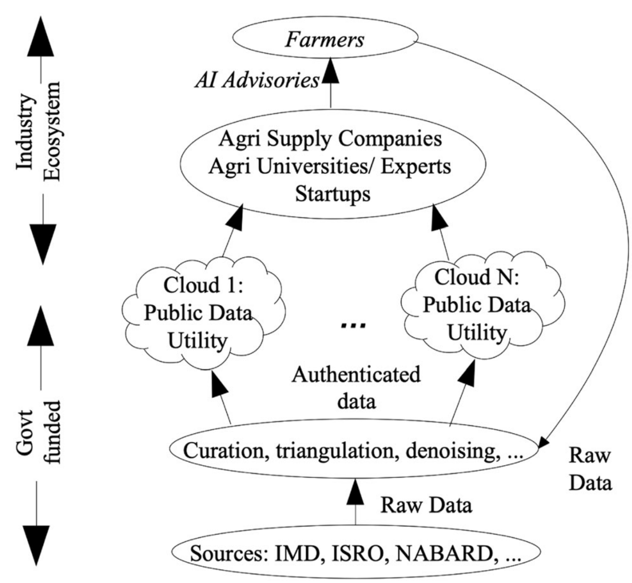


Fig. 2 Schematic of FarmerZone

processed is enormous. As traditional agriculture undergoes a transformation into precision agriculture, it is going to make a lot of demands on the Internet.

4 Requirements of the Internet

The expectation of the public from the Internet is instant, seamless global connectivity. The future expectation could be to have connectivity even outside the globe. For instance, the US, China, Europe and other countries are working to put people on the Moon starting 2024 [3]. By 2030 or later, there are expected to be habitations on the Moon. The Moon residents would want to have the same type of Internet connectivity that we get here on Earth.

It would be possible to have very high bandwidth transmission to the Moon using, say, lasers, but there is a fundamental limitation of the speed of light. The maximum round trip transmission time (RTT) for a signal or packet to go to a location within India and return is $\sim$20 ms, from India to the US and back is $\sim$200 ms, whereas from the Earth to the Moon and back is $\sim$6000 ms (6 s) (Table 2). These are fundamental limits that cannot be improved upon. The protocols used for communication must be radically different from the familiar TCP/IP in order to achieve good quality communications in Outer Space.

4.1 Nature of the Internet

A network consists of a backbone that interconnects access networks. End devices are connected to the access networks, and switching devices are used in both access and backbone (Ch. 1 in [4]).

One type of end devices commonly used today is PCs, laptops, tablets and cell phones. These are devices which are driven by Moore's law, and hence their capabilities keep growing exponentially, doubling every 1.5 years. They get replaced frequently with usage of 1–5 years. As a result of this, firmware and software upgrades are easy. When a new network protocol is developed, it can be downloaded and used.

A second type of end devices which is becoming much more important is the IoT devices, sensors of all kinds. Many of these sensors have limited computational capabilities. They often have very limited power, perhaps are dependent on solar power, and they may have to minimize the use of battery. Hence, their processing capabilities are very limited. Given the current trends, there are going to be billions of very diverse IoT (Internet of Things) devices in the near future [5]. These are devices where it is much harder to change the network protocol, network stack and so on.

Table 2 Maximum RTT

Area	RTT (ms)
India	20
World	200
Earth–Moon	6000

The third type of devices is the core switching devices inside the network. These typically last for a longer period of time, say 5–20 years. These are usually proprietary devices. Firmware and software upgrades are possible but since these come from different vendors, there is a vendor lock-in involved. Only when a vendor decides to upgrade, the firmware/software can be updated, whereas in end devices such as laptop or mobile phones there is much less vendor lock-in.

4.2 Internet: the ideal and the reality

We expect the Internet to be seamless. In the ideal Internet, anyone can access the Internet with an IP address without their identity being revealed. Every host has an IP address and any host can talk to any other host using any protocol and with good bandwidth and low delay. It is extremely flexible, and one can design any kind of application on top of this. It is also completely decentralized, and no one controls it, that is, if someone tries to block traffic on one node, the data goes through other nodes.

In the early days (1990s), the Internet was indeed seamless, close to this ideal. Then, a major problem came up with the 32-bit IPv4 mode address which could address about 1 billion nodes. Today, we have greatly exceeded that number. One solution to this is IPv6. IPv6 gives a 128-bit address and that is enough for every grain of sand on the earth to have its own IP address. With IPv6 every host and every IoT device can have its own IP address. But IPv6 has not been implemented widely. Instead of IPv6, today we have NAT devices, proxies and applications with a central server. Rather than having a decentralized, peer-to-peer Internet, we have gone to a relatively centralized Internet. The Internet, in some sense, has become fragmented into islands which are connected by gateways and the gateways can be shut off easily. This is very different from the dream that the pioneers had of the Internet.

A second problem is highly variable latency due to propagation delays ranging from microseconds for co-located hosts to 100 s of milliseconds for hosts in different continents. The effect of latency is that content that is in a remote country takes longer to access than content that is local. A couple of solutions to this have come up. One is to have content distribution networks where the content of the server located in a distant place is mirrored on local sites. There are many content distributions networks. One problem with this is that big websites can have an agreement with content distribution networks and have their content appear very rapidly anywhere in the world. Small players can afford only one website which will be fast in the local region and slow everywhere else. Today, the Internet is increasingly becoming controlled and dominated by a very few large corporations.

Some of the problems of the Internet have come about not because there are no solutions. IPv6 is a solution, only it is not been rolled out, which is primarily because the networks are hardware-based. In order to roll out IPv6, all the current hardware need to be replaced, which is difficult and expensive. There are other protocols too which may need hardware replacement.

5 SDN

In future, to address rapidly and often unpredictably changing demands, technological solutions need to be flexible and adapt quickly. This has led engineers in various fields to develop highly adaptable solutions. For example, evolutionary robotics allows robots to adapt and respond to their changing environment [6]. In car manufacturing, flexible assembly lines allow for flexible and agile car production to manage production with user-specific customization without introducing waste and delay or compromising quality [7]. The Internet community too has responded to demands of seamless operation in a multi-vendor scenario with rapid changes in the number of users and their data demands. *Software Defined Networking (SDN)* is one such solution (Chap. 5 in [4]).

Software Defined Networks (SDN) can play an important role to address the challenges facing the Internet. Instead of integrated hardware routers that both switch and decide on policies, SDN has a separate data plane and a control plane. The *data plane* consists of the switches and the routers that switch and forward data. The SDN *control plane* consists of software in a central server. It looks at policies and downloads the appropriate instructions to the switching devices. As the control plane is implemented largely in software, it can easily be changed to radically alter the nature of the network.

The flexibility of SDN makes it potentially a good solution to the problems plaguing the Internet today. For instance, rollout of new protocols and routing policies to support novel applications will require only software updates to the server-based control plane. The widely distributed hardware data plane need not be touched.

5.1 SDN challenges

However, there are a number of challenges in widespread deployment of SDN in the Internet. These include scalability of the SDN control plane, rollout of SDN, security of SDN, the impact of IoT, wireless mobility, information-centric networks and SDN standards. We will talk about some of these.

One of the challenges is *rollout*. IPv6 suffered because there was no practical method worked out in advance by which IPv4 devices could be quickly and completely replaced with IPv6 devices. Unless there is some way of replacing the millions of hardware-based routers with SDN-based routers over a short time period, the SDN promise will not be fulfilled. As the Internet is increasingly a critical infrastructure in our day-to-day lives, a major outage of the network becomes unacceptable. The cost is extremely high. So, rolling out SDN must be done in a phased manner that does not disrupt the network. During such a phased rollout, the system might suffer from poorer performance and it becomes more vulnerable.

Having the control plane on a single server is not a *scalable* solution. Further, the central server is a single point of attack. It is very vulnerable from the security point of view. So, an alternative is to have a distributed control plane. Here, a number of SDN servers make the decisions and control the switching. This is more scalable and a bit more secure. However, it does have some problems. One is the problem of *cascading failure*, that is if there are a dozen servers and if the servers start failing one after the other, the load on the remaining servers becomes high and those servers are also likely to fail. Soon, we are back to the single server configuration bearing the entire load with all its limitations.

In SDN, the applications that control the switches may be developed by third party vendors and not by the vendors of the switches themselves. Ensuring that all these devices are individually secure and that collectively also they are secure is very complex. In such a system, the whole is only as secure as the weakest link. This can cause serious security problems [8].

Another important issue researchers are working on is the mobility of wireless devices [9]. As the device moves, it should optimize performance by connecting to the best access point. If all the access points are controlled by one administrative entity, then the IP address is likely to remain the same and it is easier to implement. However, if they are controlled by different entities each having its own set of assigned IP addresses, the IP address of the mobile device will change and there are issues. The OpenConfig consortium works on standards in this area.

6 Conclusions

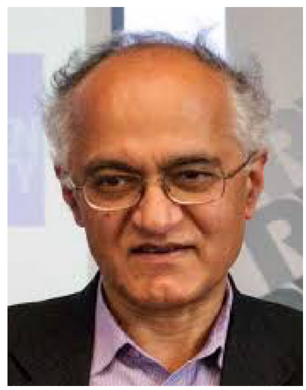
The rate of change in technologies and in society in general has been increasing over the past thousands of years. The rate of change is now increasing exponentially. Disruptive technologies are taking the world by storm faster and faster. We are going to see unprecedented and unimaginable changes in the next 50 years. In future disruptive changes will be perhaps spreading literally at the speed of light, because packets travel on the Internet at close to the speed of light.

Hardware-defined networks of the past have resulted in serious issues with the Internet losing some of its essential and desireable characteristics. SDN is one possible solution to this. Whether SDN meets the promise or not depends on various challenges, particularly security issues, scalability and the plan for the rollout of SDN to replace all the hardware devices of today. Because of its potential to lead towards a better Internet and the major challenges that remain to be tackled, SDN will remain a fertile field for researchers and product vendors for some time to come.

Acknowledgements I am grateful to Samar Agnihotri for discussions that clarified the sections on the Internet and SDN, and to Anita Mary Rajam for preparing the initial draft from the transcript of my talk. The FarmerZone™ Project is funded by the Department of Biotechnology, Govt. of India. FarmerZone is a registered trademark of DBT.

References

1. Morris I (2011) Why the west rules for now. Profile Books, London
2. FarmerZone™ Project. https://www.farmerzone.in/, IIT Mandi/DBT, 2018–2020. Accessed 31 July 2019
3. Special issue on Moon Base, IEEE Spectrum, July 2019
4. Kurose JF, Ross KW (2017) Computer networking: a top-down approach, 7th edn. Pearson, London
5. A Banafa (2017) Three major challenges facing IoT. IEEE Internet of Things Newsletter, March 14, 2017. https://iot.ieee.org/newsletter/march-2017/three-major-challenges-facing-iot.html. Accessed 31 July 2019
6. Doncieux S, Bredeche N, Mouret J-B, Eiben AE (2015) Evolutionary robotics: what, why, and where to. Front Robot AI. https://doi.org/10.3389/frobt.2015.00004. Accessed 31 July 2019
7. Schmitt B Inside Toyota's Takaoka #2 Line: the most flexible line in the world. https://www.thedrive.com/tech/26955/inside-toyotas-takaoka-2-line-the-most-flexible-line-in-the-world. Accessed 27 Jan 2020
8. Ahmad et al. (2015) Security in SDN: a Survey. IEEE Commun Surv Tutor 17(4):2317–2346
9. Gacianin H, Ligata A (2017) WiFi self-organising networks: challenges and use-cases. IEEE Commun Mag 55(7):158–164



Dr. Timothy A. Gonsalves is the Director of IIT Mandi since 2010. He completed his B.Tech in electronics engg. from IIT Madras in 1976, Master's in electrical engg. in Rice University, Houston, Texas, 1979 and his PhD from Stanford University, California, 1986. He was a co-founder of the TeNeT Group (Telecommunications and Computer Networking) of IIT Madras, 1992-present. He has helped IIT alumni found R&D companies including Midas Communications, Banyan Networks, NMSWorks Software and ISoftTech. He founded Nilgiri Networks, Ooty, for telecom software development in a small town. He has served as a Director of NMSWorks Software Ltd and IIT-M Rural Technology Business Incubator; has been a Consultant to State Bank of India, Institute for Development and Research in Banking Technology (IDRBT), and 3i Infotech. Member, Technology Committee, Mobile Payment Forum of India (2007-10).