Future Evolution of Network Technologies

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*'For tribal man space was the uncontrollable mystery.
For technological man it is time that occupies the same role'
Marshall McLuhan 1951*

In the ever-changing world we live in, some of us still remember faintly the days without electricity, and when for the first time we received electricity at home the impact it had in our lives. Electric light changed our lifestyle, it enabled us to work more efficiently, to increase productivity, to stay later at night, it powered refrigeration which improved our health, then the telephone, radio, and television for improved communications. Today electricity is ubiquitous and it supports everybody's lives. Currently and within the last few tens of years we are experiencing the effects of computer connectivity made possible via networks and the Internet. The social changes this is bringing to our lives are or soon will be felt. Since the industrial revolution we learnt to survive by becoming professional, we have empowered money so that it eclipses everything, communication has become essential and knowledge and innovation has become property. The workforce is now highly focused and specialized and self-sufficiency is unnecessary because we depend on one another. Our society has evolved from the village, where one has to be a polymath and master of all trades to survive to the city folk, where one can afford to specialize. In my profession when I go to my office, I go in order to be interrupted. I go in order to meet people students, staff, and work collectively. I do the 'thinking' at home, in the train, or airplane. We have created a two-class society with those who spend a lot of time to save money, they are usually poor and the rich who spend a lot of money to save time. I can no longer afford to buy an orange because the opportunity cost is huge. I can afford to buy them by the crate. We cannot afford to wait in the queue. Think about how much money could you earn while you wait in the queue. This has become prohibitive. Personally I have no time to do gardening, house decoration, cleaning, maintenance. Those jobs have to be outsourced. In the new economy we live in, knowledge is wealth, what is bigger is not necessarily better, we have more opportunities but fewer guarantees, everything happens faster, everything is exponential, product demand comes in peaks and return on investment is bigger than ever before. The nature of companies and work are changing. Traditionally companies employed full-time people. This evolved into virtual companies with a core management and a smaller project team, to virtual cooperative, which is a team and software, to a logistics company which has a genie, to only 'personal assistant' software to future people-less corporations. The new economy is also about perception, the 'brand', 'quality', 'timeliness', 'trust', 'delivery', and 'taking the 'pain' away. The traditional customer delivery channels are changing and the routes to reaching and satisfying the customer needs are changing. It can be channeled via the media, telephone, mobile phone, PCs, WAPs, appliances, transport, petrol stations and every screen and device is an opportunity. The future of business is very much about 'time'. Time, for processing and delivering, information has become the enemy and during the years we have developed new techniques for their demise. We do not like waiting, we often cannot afford the time waiting. When I was teenager, I would wait for ages in the queue to see a film in the cinema. We do not like doing this anymore. We can watch it at home whenever we want on demand and in comfort. We have become an instant gratification society. We traditionally use letters and telegrams that take weeks to arrive to their destination, telex, analogue and digital fax and recently email which take minutes. We used to keep products for longer. Today the internet, which allows delivery of knowledge and information in minutes and seconds has allowed the development of e-working and e-commerce. We now create knowledge products and like physical products they have a value. The value of knowledge, f(t), decreases in time and has a half life. Bits constitute information and knowledge and therefore the value of bits has a half-life. The half-lives of our employers, our jobs and our degrees gets shorter in time. The value half-life of an engineering degree used to be a life time 20 years ago, today it is only 5 years. There is a cost C in replacing information which depreciates, with new and more valuable. The average value accumulated per unit time from information is $\left[\int_{t=0}^{x} f(t)dt - C\right]/x$. The time when this function has a maximum then it is the best time to change our information/product and renew it. The maximum is when $\left[\int_{t=0}^{x} f(t)dt - C\right]/x = f(x)$. This simple and crude example illustrates how we operate in business and sometimes in life, it predicts when we should develop new products, replace our outdated software and perhaps when we need to sell our company car in favour of another.

When we process, transmit and receive information we would like this to be very fast in order to have competitive advantage, we would also like it to be reliable, from anywhere and anytime.

This is possible today more than ever before, but how did it all happen? The rise of the computing power in parallel to telecommunication advances and consumer electronic devices has certainly something to do with it [2]. According to Moore's Law we are experiencing a doubling of the computing power and density of electronics, magnetic and optical storage and in the size of embedded software every 18 months. If we put these growth factors into perspective by observing for instance, the historical progress in physical transportation, we may wonder why systems are still subject to evolution rather than to revolution. Progress in transportation by a factor of 1000 took centuries to occur: a horse and cart, an early automobile and a supersonic aircraft cover the distance of 30km in one day, an hour and one minute respectively. Why can we cope apparently so easily with exponential growth in present day technology? According to Claasen's law the usefulness is a logarithmic function of technology [3]. The perceived progression in systems is a linear function of time. Systems such as TV receivers, telephone sets, software have become more complex exponentially, their perceived usefulness, however, has improved 'only' linearly. This leads to evolution rather than revolution.

Although it took some 100 years for the telephone network to be established, it only took some 50 years for computing and only 20 years for the PC. Who would have predicted that since Netscape in 1995 launched the web in the mind of the public that within 2000 days we would be sending 3.5 trillion email messages each year and that we would have collectively created 3 billion public web pages? More recently, the mobile phone took just 11 years for the UK population of 60M to purchase 45M mobiles. Interestingly in some 3rd world countries the mobile phone is the only generation of phone they have or experienced. The parallel technological progress in lasers, LEDs, fibre optics, microprocessors, display and storage technologies signal processing, and network technologies and their interdisciplinary integration into products which looks like a technological convergence has allowed anywhere and anytime connectivity. Fibre optic links allow Terabit/s capacities per fibre today making global broadband communications possible and limited by the speed of light pulses. The complementary use of frequency division multiplexing and optical wavelength division multiplexing has allowed us to capitalise on the huge bandwidths available by low loss silica optical fibres and to couple to traditional legacy technologies. Combined with optical amplifiers, and tunable optical wavelength laser sources, optical networks have become a reality, eliminating electronic signal repeaters. The span of such optical networks is trully global and they carry the majority of the global voice and internet data traffic.

At present, we carry PCs with great computing power, having >1GHz clock frequency with >125Mbyte RAM and >30 Gbyte hard drive. Unfortunately they come with modems of merely 56kbit/s. Considering that your digital camera images are 250kByte, music and movie files 2Mbyte, it is clear that your modem is your bottleneck in communications from inside your home. You have to wait a long time to download your data. It is known that the old voice oriented telephone network has not been designed to cope with Internet traffic. Who would have thought that at least in the UK, and in most European countries, there would be so much unused fibre optic bandwidth outside your door, so much computing power inside the home, and yet we connect with only a 56 kbit/s modem to the outside world. The telecommunication companies and CATV organisations have not yet delivered broadband in the home.

Of course within the locality of businesses and larger organizations the use of LANs has alleviated somewhat this problem. LANs have changed also in orders of magnitude from 10Mbit/s to 100Mbit/s and now 1Gbit/s.

We can consider that AT&T in the US handles 130million calls per day. Assuming 6 minutes/call at 64 kbit/s this gives 3Petabits/day, i.e. 3 million billion bits per day. Assuming 3 hrs/day (8:1 peak to average ratio), two way talking (doubles the rate), and reducing the rate by a factor of 3 for silence, this is only 185 Gbits/s. Although a billion bits/sec is really fast, the speed of light which carries the information across the USA say is not fast enough! (200,000 Km/s). The reason is that when we are transmitting at Mbit/s rates, we are still limited by the transmission time of our transmitters. The delay of transmitting the bits in the cable is smaller than the propagation time of light pulses in fibre optic cables. At Gigabits/s transmission speeds we have minimized the transmission speed and the real delay is now propagation time of light pulses in fibre optics, in other words we are limited by speed of light, which unfortunately we can do nothing about. From being bandwidth limited in other words, we are now latency limited. We are moving in times when the demand for faster access technologies from our homes, the office and from ISP providers is increasing and this demand soon will eventually be satisfied. Such demand will bring us to the age of Petabit/s links and networks. Petabit/s networks will require fibre optics and Dense Wavelength Multiplexing with Optical Amplifiers across the optical band.

In recent times we experiencing growth in demand for communication on the move and within the last few years we have also seen mobile communications to become first an accepted and subsequently a necessary part of our lives. We need to have access to the information and knowledge which we can have in the office, while we are on the move, while we are at the airport, in airplanes, in cars, motorways or stations. We are even prepared to pay significantly for communications on the move. The advent of 2G telephony the SMS and mobile internet access show the potential for a wireless future. Mobile telephony is not enough and we are preparing ourselves for a nomadic life where we work on the move and we need fast access to broadband data, telephony, and the internet connectivity. The financial model for a 3G evolution has not been worked out yet, and it is a very difficult and expensive task after the hugely expensive purchase of new frequencies for telecommunication operators to provide us with wireless broadband.

Frustration at the grim prospect of wireless broadband delivery on the move, and at home, has triggered work in alternative low cost ways of eliminating bottlenecks. We have seen the start of installations of 802.11 wireless LANs. We have seen communities beginning to be formed using wireless access points in the streets. Initial 802.11 wireless systems are being developed with speeds from 2Mbit/s to 50Mbit/s, with distance from 100m to 10 km.

There also seems to be a growth of ad-hoc peer to peer or parasitic networks, which use individual short-range links connecting devices on the move without the need of a centralized node to coordinate connectivity. Such networks offer today easily 2Mbit/s data rate on the move.

What such networks are really good at is finding different transport mechanisms for different needs. HTTP is not the be-all and end all of transport mechanisms. What peer to peer networking has shown is that the idea of client-server is an attitude about transactions but not an attitude about machines. Peer to peer networking has demonstrated that a machine can be a server to one machine and a client to another, or a client and a server at the same time. What is changing in the web services world is the notion that web browsers and servers are separate things. We learn that Domain name system (DNS) is not the only way to address the IP network, that aggregated resources are either more reliable or more scalable than having all the applications centralised.

Bluetooth technology seems to the suitable for peer to peer parasitic networks and operates at 1Mbit/s short range link up to 100m. Although 802.11 can be used for the 'last mile', Bluetooth can be used for a new trend, called Personal Area Networks, (PANs).

As the number and the variety of new electronic devices grows exponentially, devices such as PDAs, cameras, watches, 'human body sensor' also become smaller, more powerful and efficient in power consumption. Wearing smart clothing with sensors monitoring our health or populated with miniature communication devices allowing us to be connected to any services we desire on the move. We envision a future evolution in embedding devices with high computing power and internet connectivity first around and within our homes, then around our bodies (wearables) and eventually as implants within our bodies.

Wearables offer the option of a personal computer that is worn as comfortably as clothing, and interfaces in a human-centric way, using head-up-displays, unobtrusive input devices, wireless networking, and it should be worn much as eyeglasses and a host of other context sensing and communication tools. Wearables solve the problem of portability and provide lightweight processing power compatible to the human body. It is invaluable to many people, such as those working on the road, technicians, doctors, specialists, production line workers who need computer assistance. In the military, to pilots who need to absorb vast amounts of data while they operate other controls and to the consumer markets, in products such as electronic contol books remote controls, games watches and toys.

It is hoped that wearables will be designed so as we interact with computers in much more natural ways, which allow us to do what we want in a natural less laborious way. A personalized network space around our body, which can network with other people's space when we meet and shake hands.

We have demonstrated that we can control home appliances via the internet, your refrigerator to be able to warn you or even order for you when food stock is low and that it is possible for appliances to 'talk' to each other. When you return home tired from work and you put a pizza in the oven, you do not want to read how long to cook it for in order to burn it, you want the oven to read from the package the settings it needs and cook it for you. These are examples of how valuable 'time' has become for us, how networks help us connect easier and save us time, allowing us to focus on what we wish to spend our time on.

The networking of such devices for sharing data would be facilitated with Bluetooth. Such networking trends, will most likely be infrastructure-less and wireless. Our environments will become smart (desks, walls, vehicles, watches, belts, etc) will come alive with such technology as actuators, sensors, logic, processing, storage, cameras, microphones, speakers, communication. We will find that the Internet technology will be embedded everywhere in our physical world and it will be as available as electricity is today. In home networks we would soon wish for PANs which are of high performance.

Performance can be thought of as the ratio of spatial capacity by power consumption, cost and form factor:

$$Performance = \frac{Spatial\ Capacity}{Power \times Cost \times Size}$$

$$in \frac{bits/\sec/\ square\ metre}{Watts \times \$ \times cubic\ metre}$$

Low cost low power consumption technologies will therefore become much more important in the future. The bandwidth requirements for wireless connectivity are eased when the wireless network active radius is smaller. That means shorter link distance or cell radius. This allows frequency reuse of the precious frequency spectrum. However, new frequencies are available in the millimetre wave region, frequencies which are not suitable for long range links due to atmospheric absorption, which however allow short link range to 500m. Such frequencies offer us with opportunities for a better wireless and broadband future.

Wireless technologies, which have ability to support local positioning and tracking functions, will become important. We should be able to locate our children at any time and anywhere they are located when they are not with us, and be able to locate missing cars or when the cars are being operated while unattended for example.

Another area recently noted affecting networking and our lives, is the proliferation of chaotic behaviour. When people and devices with good connectivity are clustered, they tend to do things at the same time hence they get synchronized. When there is a car accident on the motorway for example, and there is a traffic jam, we all tend to make phone calls simultaneously with mobile phones. Such correlated activity and similar attractors tend to happen more often than ever before and for the mobile phone network it causes a crash. Soon there will be more things/devices online than there will be people on earth, and the devices will be able to handle larger files more often, making the situation even worse. In other words, as a result of nonlinearities, large scale of devices connected with responsive networks trigger chaotic events in shorter timescales than ever before, and we can now notice them within our lifespan. The study of complex systems and networks is a new challenge we face. The behaviour of clusters of peer to peer networks is important in view of the proliferation of huge numbers of new electronic devices which will be connected in the future seamlessly. The benefits of such collective and complex systems are that they are adaptable, evolvable, resilient, boundless, hide novelty due to their sensitivity to initial conditions and can be terrifyingly powerful. (As someone who has been attacked by a swarm of bees may live to confess). How to control such systems and networks is very important since there is no authority, no single node is in charge, and can therefore be guided like herds guided by a shepherd. They are non-optimal because they are redundant, they are difficult to predict and to understand and they are non-immediate since it takes time for the collective behaviour to surface. We must therefore experiment with the complexity of ad-hoc peer to peer networks in order to try to understand their behaviour in order to predict and avoid uncontrolled chaos within our new generation of networks.

The over-provision of bandwidth may be desirable for the future in order to alleviate chaos, and therefore we cannot avoid the use of optical fibres and in some special cases, optical wireless becoming the primary backbone for broadband provision for future networks.

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