FOUR LAWS FOR TODAY AND TOMORROW

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ABSTRACT

For the last twenty years, one field has had a very important impact on our lives and economy. Related to technology, some observations in IT and ICT fields, started in the mid-seventies would have an impact in the next decade. Very dramatic and fast changes on the telecommunication technology and on the theory of information in general were defined by four rules from which three are non-technical and were defined by people who belonged to the business world rather than to the science field. Shannon (1947), Moore (1965), Metcalfe (1985) and Gilder (1990s) defined the fast development of the ICT and the telecommunications sector. Their formulations would become some sort of laws which will be valid throughout the first decade of 21st century.

RESUMEN (in Spanish, no more than 200 words)

KEYWORDS: Gilder's Law, Metcalfe's Law, Moore's Law, Shannon's Law,

1. INTRODUCTION

Today, every term in the computer and telecommunication field has the prefix "e-", obviously, to refer to the "electronics" era. Those two, character "e" and symbol "-" are in some cases an "interface" between computers (IT in general) and telecommunications (ICT in general). Prefix "e-" today is everywhere: "e-mail", "e-business", "e-government", "e-marketing", "e-… Even hidden shortness had an "e-" connotation: B2B (Business to Business), B2C (Business to Consumer)… What is impressive about them is the unseen expansion they have had up to now.

2. PERIOD OF HIGH PROSPERITY

The period between the middle of the nineteenth and the middle of the twentieth century represents a remarkable period in the history of science and technology. During this epoch, several discoveries and inventions removed many practical limitations of what individuals and societies could achieve. Especially in the field of communications, revolutionary developments took place such as high speed railroads, steam ships, aviation and telecommunications.

It is interesting to note that as practical limitations were removed, several fundamental or principal limitations were established. For instance, Carnot showed that there was a fundamental limit to how much energy could be extracted from a heat engine. Later, this result was generalized to the second law of thermodynamics. As a result of Einstein's General Relativity Theory, published in 1915 (his Special Relativity Theory was published in 1905 and it is known as Einstain-Maric theory; Mileva Maric was Albert Einstein's first wife.)1, the existence of an upper velocity limit was found. Very important inventions, which lead to the supreme frontiers, are Maxwell's Theory of Electromagnetism (James Clerk Maxwell was who linked all known laws of electricity and magnetism at this time, in 1865). Maxwell was first to state that electromagnetic waves have velocity of light in space. Albert Michaelson and Edward Morley conducted the first test of light speed in 1887. [1,2] Other examples include Kelvin's absolute zero, Heissenberg's uncertainty principle and Gödel's incompleteness theorem in mathematics. After publishing two papers in the American Journal of Science and Transactions of the American Institute of Electrical Engineer in 1894, Michael Pupin patented in June 1900 two patents and opened filed of long distance telephony.[2] His main publications are "On Electrical Resonance," "On Long Electrical Waves," and "Wave Transmission Over Cables." In total, Pupin acquired 24 patents and they made him a wealthy man. The first patent dated from 1894 and the last one from 1923. The inventions were in the fields of telephony, telegraphy and radio. He became world famous inventing the process of "pupinisation", which made very long distance transmission of text and speech possible; thus, this process was given his name, Figure 1.

Figure 1. Michael Idvorsky Pupin (1854-1935)

Bell was the inventor of the so-called "short distance telephony", Pupin of the "long distance telephony". Transmitting the data over a communication channel was described by Claude Shannon. Shannon's Channel Coding Theorem, which was published in 1948, seems to be the last of such fundamental limits, and one may wonder why all of them were discovered during this limited time-span. One reason may have to do with maturity. When a field is young, researchers are eager to find out what can be done – not to identify borders they cannot pass. Since telecommunications is one of the youngest of the applied sciences, it is natural that more fundamental laws were established at a late stage. Other inventions in these fields led to point-to-multipoint connectivity. With the installation of the first transatlantic cable between the USA and the United Kingdom in 1956 with only 36 simultaneous channels and the launch of the first geostationary commercial satellite Intelsat I with 240 integrated circuits in 1965, the era of connectivity and telecommunications started. This was phase one. The second phase started in 1989, according to the famous magazine the Economist: The world is a global village.

"Round II" is the new era of globalization, era which we are now in. As *The Economist* has noted, today's era of accelerated development is built around failing telecommunications costs thanks to microchips, satellites, fiber optics and the Internet. A three-minute call (expressed in 2004 dollars) between New York and London cost $342 in 1930. Today it is almost free through the Internet[3]. The slow, fixed, divided Cold War system that had dominated international affairs since 1945 has been firmly replaced by a new, very greased, interconnected system. If we did not t fully understand that in 1989, when the Berlin Wall came down, we sure understood it a decade later. Indeed, on October 11, 1998, at the height of the

global economic crisis, Merrill Lynch ran full-page ads on major newspapers throughout America to drive this point home. They published an add entitled "World is 10 Years Old." [4]
Actually, the Merrill Lynch advertising campaign in 2000 would have more accurately stated that this new era is "just ten years old".

3. LAWS WHICH HAVE EFFECTS ON TELECOMMUNICATIONS

It is clear that everybody likes to have mobile phones, one at least.. This leads to an exponential growth of telecommunications. The need of high mobility leads to the fact that everybody likes to "communicate with everybody". Throughout centuries a model of supply and demand has existed. Telecommunication services have opened new fields where spreading the technology decreased the value. It is not easy to describe this phenomenon through one law. There are four main laws; by using them, we will very precisely describe the future of technology:

- Shannon's Law
- Moore's Law
- Gilders Law
- Metcalfe's Law

Except for Shannon's Law, which is scientific, all of the others are not; they were built from forecasts and technological trends, stated years and even decades ago and, finally, they were converted into some kind of laws.

4. SHANNON'S LAW

In the present paper we will try to shed some light on the developments that led up to Shannon's Information Theory. When one compares the generality and power of the explanations on Shannon's paper "A Mathematical Theory of Communication" [4] to alternative theories at the time, one can hardly disagree with J. R. Pierce who states that it "came as a bomb"5. In order to see the connection with earlier work, we will, therefore, focus on one particular case of Shannon's theory, namely the one which is sometimes referred to as "Shannon's Formula". As it will be shown, this result was discovered independently by several researchers and serves as an illustration of a scientific concept whose time had come. Moreover, we will try to see how development in this field was spurred off by technological advances rather than theoretical studies isolated from practical life.

4.1. Shannon's Formula

Sometimes, a scientific result comes quite unexpected as a "stroke of genius" from an individual scientist. More often, a result is gradually revealed by several independent research groups, and at a time which is just ripe for the particular discovery. In this paper, we will look at one particular concept, the channel capacity of a band-limited information transmission channel with additive white: Gaussian noise. This capacity is given by an expression often known as "Shannon's Formula" (Many mathematical expressions are connected to Shannon's name. The one quoted here is not the most important one but, perhaps, the most well-known among communications engineers. It is also the one with the most immediately understandable significance at the time it was published:

$$C = W \log2(1 + P/N) \quad \text{bits/second.} \qquad (1)$$

We intend to show that, on the one hand, this is an example of a result for which time was ripe, it is exactly from a few years after the end of World War II. On the other hand, the formula represents a special case of Shannon's Information Theory presented in [5] which was clearly ahead of time with respect to the insight generally established.

“Shannon’s Formula” (1) gives an expression for how many bits of information can be transmitted without error per second over a channel with a bandwidth of *W* (Hz), when the average signal power is limited to *P* (watt), and the signal is exposed to an additive, white (uncorrelated) noise of power N with Gaussian probability distribution. For a communications engineer of today, all the involved concepts are familiar – if not the result itself. This was not the case in 1948. Whereas bandwidth and signal power were well-established, the word bit was seen in print for the first time in Shannon’s paper. The notion of probability distributions and stochastic processes, underlying the assumed noise model, had been used for some years in research communities but was not part of an ordinary electrical engineer’s training.

The essential elements of “Shannon’s Formula” are:

• Proportionality to bandwidth *W*
• Signal power *S*
• Noise power *P*
• A logarithmic function

The channel bandwidth sets a limit to how fast symbols can be transmitted over the channel. The signal to noise ratio (P/N) determines how much information each symbol can represent. The signal and noise power levels are, of course, expected to be measured at the receiver end of the channel. Thus, the power level is a function both of transmitted power and the attenuation of the signal over the transmission medium (channel).

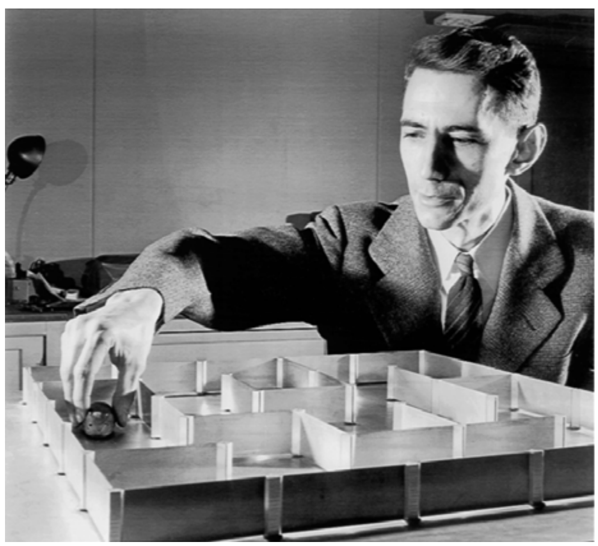


Figure 2. Claude Elwood Shannon (1916-2001), the founder of the Information Theory, had also a practical and a playful side. The photo shows him with one of his inventions: a mechanical “mouse” that could find its way through a maze.

If we want to simplify the theorem this can be done through the question: *How do bandwidth and noise affect the rate at which information can be transmitted over an analog channel?* Surprisingly, bandwidth limitations alone do not impose a cap on maximum information transfer. This is because it still is possible (at least in a thought-experiment model) for the signal to take on an infinite number of different voltage levels on each cycle, with each slightly different level being assigned a different meaning or bit sequence. If we combine both noise and bandwidth limitations, however, we do find there is a limit to the amount of information that can be transferred, even when clever multi-level encoding techniques are used. This is because the noise signal obliterates the fine differences that distinguish the various signal levels, limiting in practice the number of detection levels we can use in our scheme.

The Shannon Theorem states that given a channel with information capacity C and information is transmitted at a rate R, then if

$$R \leq C \quad (2)$$

there exists a coding technique which allows the probability of error at the receiver to be made arbitrarily small. This means that, theoretically, it is possible to transmit information without error up to a limit, C.

The converse is also important. If

$$R > C \quad (3)$$

the probability of error at the receiver increases without bound. This implies that no useful information can be transmitted beyond the channel capacity.

5. MOORE'S LAW

In 1965, Gordon Moore, Director of the Fairchild Semiconductor's Research and Development Laboratories, wrote an article on the future development of the semiconductors industry for the 35th anniversary issue of the Electronics magazine. In the article, Moore noted that the complexity of minimum cost semiconductor components had doubled per year since the first prototype microchip was produced in 1959. This exponential increase in the number of components on a chip became later known as Moore's Law. In the 1980s, Moore's Law started to be described as

Processors power is doubling the number of transistors on a chip every 18 months.

At the beginning of the 1990s, Moore's Law became commonly interpreted as the doubling of microprocessor power every 18 months. In the 1990s, Moore's Law became widely associated with the claim that computing power at fixed cost is doubling every 18 months.[7]

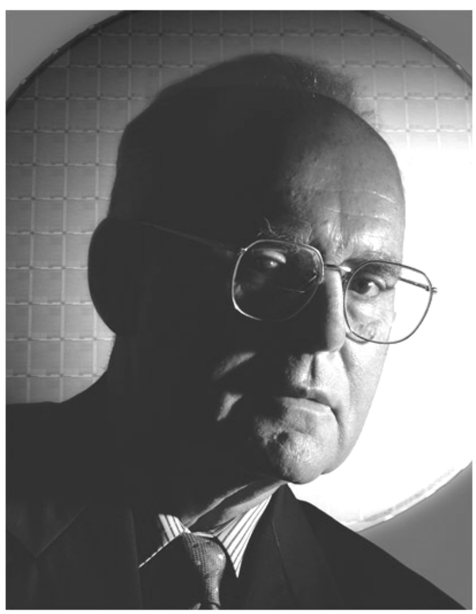


Figure 3. Gordon Moore

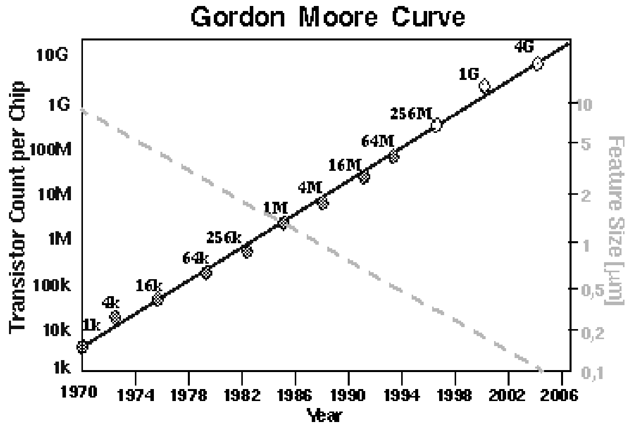


Figure 4. Moore's Law

Of course, if Moore's Law is valid, no matter the exact nature of physical limits, the exponential development means that the limits are only a few technological generations ahead. The order of magnitude errors in our current estimates of the ultimate limits of chip technology will create, at most, a time error of a few months when they become bottlenecks in chip technology. As a result, it is easy to predict that Moore's Law will become invalid soon. Speculations on the extended lifetime of Moore's Law are, therefore, often centered on quantum computing, bio-computing, DNA computers, and other theoretically possible information processing mechanisms. Such extensions, obviously, extend beyond semiconductor industry and the domain of Moore's Law. Indeed, it could be difficult to define a "component" or a "chip" in those future devices.
When Moore in 1965 observed that the number of components on integrated circuits seemed to double regularly, this fact was known to many people working in the area. Indeed, it took over a decade, during which Moore beçame the co-founder of Intel and its President and CEO, before this observation was called Moore's Law. During this decade, the content of the original Moore's Law, however, also started to shift.

In his 1965 article, "Cramming more components onto integrated circuits," Moore discussed the future of integrated electronics. He noted that the object of miniaturization had been putting increasingly complex electronic functions in limited space with minimum weight. Indeed, the first chip, created in 1959 by Jack Kilby at Texas Instruments was born as a reaction to the U.S. Army's Micro-Module program that tried to stack individual components as functional modules (Mann, 2000). In his 1965 paper, Moore mentioned the Apollo manned moon flight program as a demonstration that integrated circuits can be as reliable as individual transistors.

Moore went on to describe reduced costs as one main advantage of integrated electronics. According to Moore, manufacturing costs were dominated by two factors. First, the cost to manufacture simple chips was nearly independent of the number of components on the chip. In other words, the cost per component was nearly inversely proportional to the number of components. Second, Moore noted that the increased complexity of chips rapidly lead to decreasing yields in manufacturing. This quickly overwhelmed the cost advantages of cramming more components on the chip. As a result of these two cost drivers, integrated electronics had an optimal complexity of circuitry that led to most cost-efficient chips. As improvements in manufacturing led to better yields, the optimum complexity was growing accordingly.

Since the 1980s, Moore's Law has been used often and in many different ways. For example, Intel described Moore's Law on its web site in April 2002 in the following way:

"Gordon Moore made his famous observation in 1965, just four years after the first integrated circuit was discovered. The press called it "Moore's Law" and the name has stuck. In his original paper, Moore predicted that the number of transistors per integrated circuit would double every 18 months. He forecast that this trend would continue through 1975 ... Moore's Law has been maintained for far longer, and still holds true ..."

Moore himself has noted:

"I never said 18 months. I said one year, and then two years ... Moore's Law has been the name given to everything that changes exponentially. I saw, if Gore invented the Internet, I invented the exponential" [8]

And also:

‘ No exponential is forever… but we can delay

“forever” ‘

To commemorate the 40th anniversary of "Moore's Law," the Marconi Foundation at Columbia University bestowed its Lifetime Achievement Award on Gordon Moore, the law's author and an Intel co-founder. The Lifetime Achievement Award has been given to only two other people in the foundation's 31-year history. In 2000, the award was presented to mathematician Claude E. Shannon, the founder of modern information theory and inventor of the concept of the bit, and in 2003, to William O. Baker, who, as director of research and later president of Bell Laboratories, oversaw the development of a wide array of technologies that earned Bell's researchers 11 Nobel Prizes during his tenure at the helm.

6. METCALFE’S LAW

Robert Metcalfe (born 1946 in Brooklyn, New York) is an American technology pioneer who invented Ethernet, founded 3Com and formulated the so called “Metcalfe's Law”. Bob Metcalfe was working at Xerox PARC in 1973 when he invented Ethernet, a standard for connecting computers together over short distances. In 1979, Metcalfe departed PARC and founded 3Com, a manufacturer of computer networking equipment.

In 1980, he was the recipient of the Association for Computing Machinery Grace Murray Hopper Award for his work in the development of local networks, specifically the Ethernet. In 1990, Metcalfe departed 3Com following a dispute with the board, and has spent his time writing and public speaking since then. He is currently a General Partner at Polaris Ventures. He graduated from MIT with two Bachelor's degrees, one in electrical engineering and another in business from MIT's Sloan School of Management. He earned his Ph.D. from Harvard University, with a thesis on packet switching (which was actually written while working at MIT's Project MAC).

Metcalfe's Law [9] states that the value of a communication system grows as approximately the square of the number of users of the system (N^2). Since a user cannot connect to itself, the actual calculation is

$$N(N-1)/2, \text{ or } (N^2-N)-2. \qquad (3)$$

The law is often illustrated with the example of fax machines: a single fax machine is useless, but the value of every fax machine increases with the total number of fax machines in the network, because the total number of people with whom you may send and receive documents increases. This contrasts with traditional models of supply and demand, where increasing the quantity of something decreases its value. This is clasical mathematical formula for calculating numbers of diagonals in polygon.

But, there are new laws which oppose Metcalfe’s Law. In March 2005, Andrew Odlyzko and Benjamin Tilly [10] published a preliminary paper which concludes Metcalfe's Law significantly overestimates the value of adding connections. The rule of thumb becomes "the value of a network with n members is not n squared, but rather n times the logarithm of n."

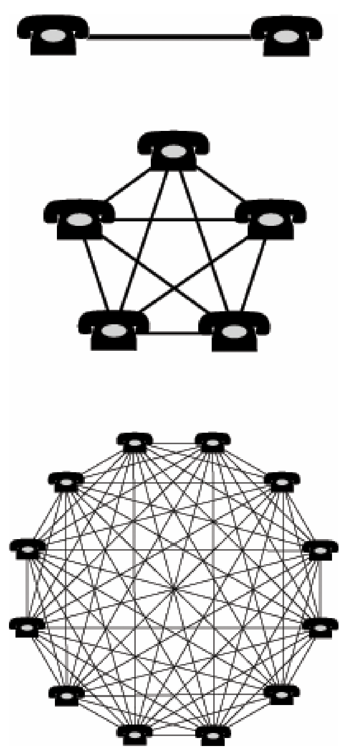
"The fundamental fallacy underlying Metcalfe's (Law) is in the assumption that all connections or all groups are equally valuable," the researchers report.

If Metcalfe's Law were true, there would have been tremendous economic incentives to accelerate network mergers that in practice take place slowly. "Metcalfe's Law provides irresistible incentives for all networks relying on the same technology to merge or at least interconnect."

The researchers propose a less dramatic rule of thumb: the value of a network with *n* members is not *n* squared, but rather *n* times the logarithm of *n*. That means, for example, that the total value of two networks with 1,048,576 members each is only 5 percent more valuable together compared to separate. Metcalfe's Law predicts a 100 percent increase in value by merging the networks.

It is not a merely academic issue. "Historically there have been many cases of networks that resisted interconnection for a long time," the researchers said, pointing to incompatible telephone, e-mail and text messaging standards. Their network effect law, in contrast to Metcalfe's, shows that incumbent powers have a reason to shut out smaller new arrivals.

When two networks merge, "the smaller network gains considerably more than the larger one. This produces an incentive for larger networks to refuse to interconnect without payment, a very common phenomenon in the real economy," the researchers conclude.



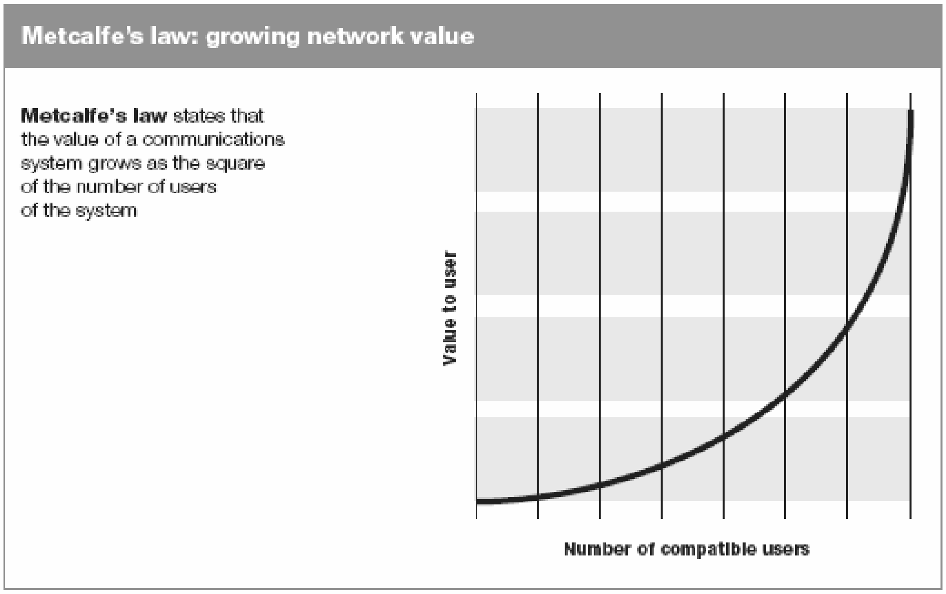


Figure 6. Metcalfe's Law

Practically, this work of Odlyzko and Tilly will correct Shannon's Law. It is obvious that the telephone or the Internet subscribers do not need to interact with everybody in the network.

7. METCALFE'S LAW

This series of articles by George Gilder provide some interesting technological and cultural background[11]. He stated that

"Bandwidth grows at least three times faster than computer power."

Practically, telecommunications bandwidth doubles every 6 - 9 months.

Figure 8. Metcalfe's Law

This leading to the fiber sphere. Fig 9. shows this demand on diagram. Main demand is transferring the motion picture and TV signal to the subscriber. Minimum requirement is 2 mb/sec. Fiber optical cables are one of the solutions.

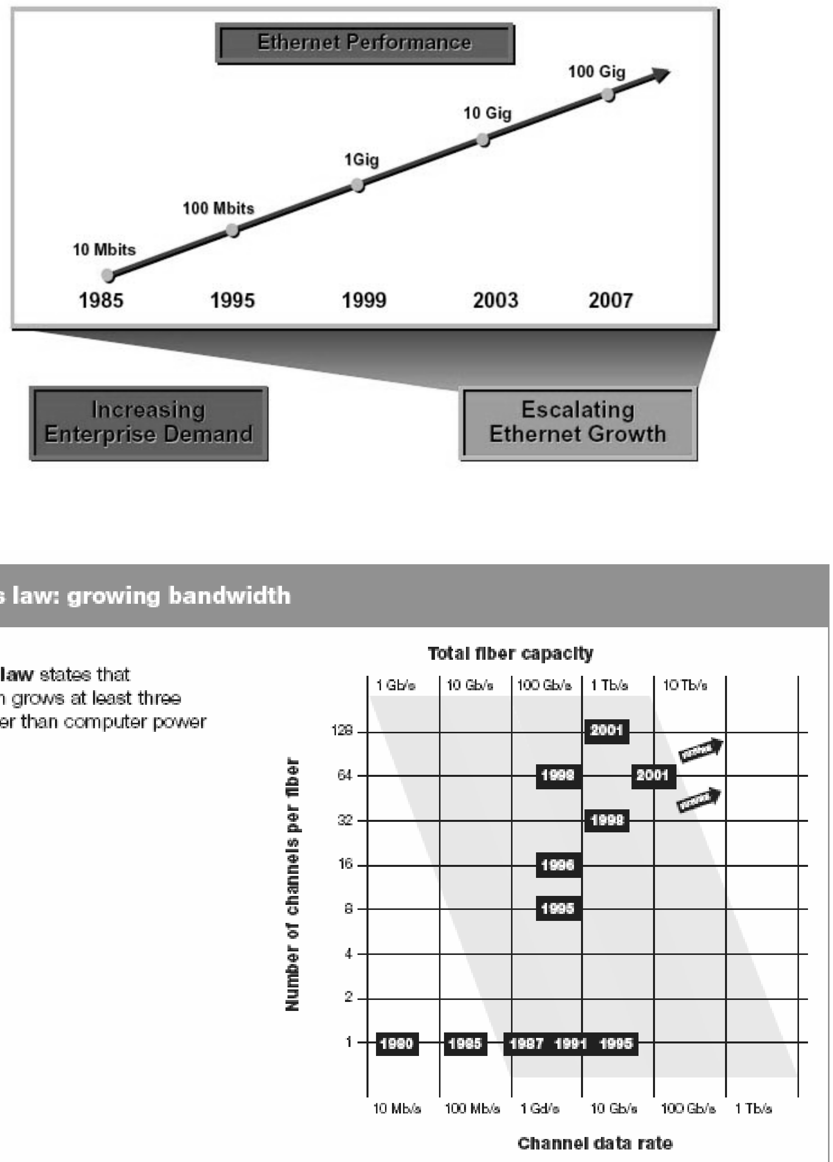


Figure 9. Demand for data transferring via optical cable

8. WHAT KIND OF OPPORTUNITIES WILL BE POSSIBLE

Sophisticated electronic systems in vehicles are nothing new. Sensors and feedback systems began years ago to look after things such as on-board engine management and fault diagnostics, traction and braking. The arrival of low-cost cellular radio and satellite networking, though, has enabled such sensors to link to a growing range of remote services. Vehicles are turning into nodes in an increasingly sophisticated network of services. The automobile industry is just one example of an industry changing

as a consequence of the Network Era[15] (The Network Era is growing a network of services around the automobile such as concierge services, multimedia content, cellular calling, theft reporting, emergency services, remote security, retail advice, remote diagnostics, e-mail, V-mail, navigation, traffic reports, auto insurance). The same will soon happen in industry after industry as the underlying technologies show no signs of slowing down. In fact, the pace of technological change is accelerating, driven by three foundation laws: Moore`s, Metcalfe`s and Gilder`s.

On its own, the effect of each law is dramatic. Taken together, their effect is compounded. The laws reinforce each other in a spiral of growing impact and value (Figure 10). More power plus more users plus more bandwidth leads to more value and increased appetite for all three.

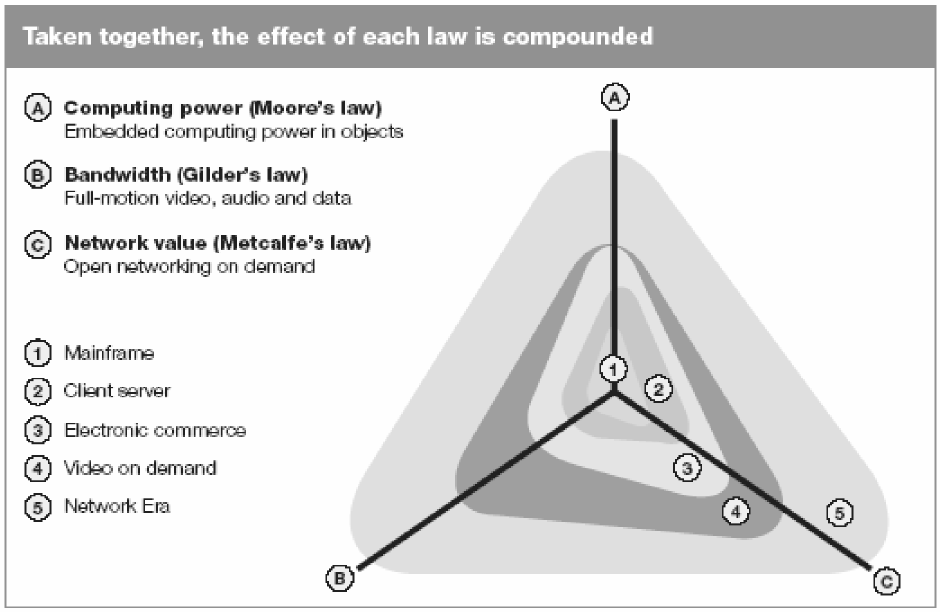


Figure 10. Compound effect of 3 Laws

The combined impact of these laws is set to transform processes, products and services.

The three laws add value through mutual reinforcement. Their pervasive impact is shown in the 3x3 matrix (Figure 11). Take

products, for instance. Moore’s law lies behind the rapid displacement of traditional analog videotape recorders by powerful, low-cost digital DVD systems. DVD players can be connected to other products such as entertainment systems at home (Metcalfe’s Law), opening the door to interactions both within the home and beyond it (Gilder’s Law).

The 3x3 matrix shows how processes, products and services are transformed			
	Processes	**Products**	**Services**
Moore's law	Informated business processes	Digitized products	Remote services
Metcalfe's law	Networked process components	Connected products	Global service networks
Gilder's law	Dynamic adaptations	Rich interactions	Customized services

Source: Professor N. Venkatraman, Boston University

Figure 11. Transformation matrix

Most products are information-rich, but that information has not been exploited. In the Network Era, it will be. Take chemicals, for example. Storing, handling and disposing of chemicals require large amounts of information to be done properly. In the Network Era, containers will "know" what they contain and how they are to be handled and used. Product specifications and legislative and control documents
-already available online- will be called up automatically from the network as needed. In the event of an accident, emergency procedures can be located and displayed immediately, and relevant external agencies notified as required.

9. CONCLUSION

From all four Laws, it seems that Metcalfe's Law significantly overstate the value of a communication network. In their place, Odlyzko and Tilly[10] propose another rough rule, that the value of a network of size n grows like *n log(n).* This rule, while not meant to be exact, does appear to be consistent with historical behavior of networks with regard to interconnection, and it captures the advantage that general connectivity offers over broadcast networks that deliver content. It also helps explain the failure of the dot-com and telecom ventures since it implies network effects are not as strong as had been hoped for.

Expectations are that growth will be exponential (or very close to exponential). Such as:

• growth in population (1.9% per year, or doubling on every 35 years-1960: 3 billions, 2000: 6 billions, 2035: 9 billions (estimated))

• growth in world consumption of energy (2% per year, or doubling on every 30 years-1970:200 quadrillion BTU, 2000: 400 quadrillion BTU, 2015: 550 quadrillion BTU) [12]

If we look in IT and ICT data[13], we will see, for most countries in the world, that exponential growth is present in telecommunications too. But growth factor is around 20% year. This rate is even higher in non industrial countries. It is obvious that acceptability in telecommunications and the ICT industry on the global level does not match Gilder's Law. It is ten times slower. Even the data shows the exponential growth, practically we are speaking of an explosion. Explosion not just about increasing the number of users but about developing new technologies (new generations of devices for data transferring come out every six months, totally new systems for data transferring - such as 4G GSM systems for mobile telephony - are launched on the market, all types of signal integrations are present, i.e., digital TV, computer and IT telephony. As a final conclusion, we envision (and expect these words arevisionary), that energy, telecommunications and means of transportations will be free (or close to free) in a very near future[14]. Explosion is like Big Bang[1].

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