# Nature-Inspired Networks
# The Telecommunications Industry Point of View

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ABSTRACT: We present an industrial perspective on the aims and applications of nature-inspired networks. This is based on a study of the British Telecom research laboratories in the UK. The highly ambitious, innovative agenda of the company is served by a broad research base including a significant investment in a range of techniques which fall under the description of 'nature-inspired'.
There is a widely held belief across the telecommunications sector that radical solutions are required to resolve current and near-future issues of management and control of complex distributed systems. In BT, the pursuit of these solutions can be divided into three themes: building and maintaining the physical network; managing the dynamic functioning of the information network; deriving utility and value from the information in the network.

KEYWORDS: networks, telecommunication, optimisation, planning, autonomous, self-organisation, evolutionary

## INTRODUCTION:

This report attempts to summarize the industrial point of view on Nature-Inspired Smart Information Systems and more precisely on its relationship with Networks. This work is based on a study conducted at the research laboratory of British Telecom.
In the same way as British Telecom at its inception in 1846, as the Electric Telegraph Company, dramatically and profoundly participated to change every aspect of the society; today BT focuses on building the foundation of the digital era to create the information age. In fact, innovation - the combination of technical know-how with commercial acumen - is even more crucial in today's fast-moving competitive world.
Today British Telecom has around one hundred thousand employees. And its research laboratories are among the leaders in the world. Because of its position and size we can presume, with a certain confidence, that what is presented here reflects the industrial interests and needs of the telecommunication industry.
This document is structured as follows. First we present a short *context* paragraph in which we explain the changes of the telecommunication industry over recent years. Based on this, we split the document in two large parts: the first focuses on what we called the *old challenges*, dealing with traditional static telecommunication infrastructures (network design and planning, network traffic management, etc.) and the second part focuses on the *new challenges*. We have grouped the last into two large themes: first how to handle automatically *networks* that are going to be *everywhere* and second how to deal in an intelligent and adaptive manner with *knowledge and social networks*. Before concluding, we present a short paragraph on what are the natural models that BT is looking at for getting *fundamental inspiration*, even though there is no identified application yet.

## THE CONTEXT

Today's BT is being transformed into a global IT, communications and networking services business for the 21st century. Billions of pounds are being invested in new networks, new services and new technologies - not just to provide telephone services but internet, data, broadband and mobile services too. And they are pushing back the frontiers of technology to offer services like virtual markets, electronic commerce, broadband, mobility and security.
In fact, in the last years the leading companies in the telecommunication business have shifted their interest from the traditional management of the physical telephony network (i.e. their infrastructures) to the management of all sort of new networks: ranging from sensor networks to social networks.
These two extremes illustrate the two new strategic objectives of any telecommunication company today. On the one hand the self-management of all sorts of networks. In fact, in the next few years all sorts of networks are going to invade our space: home networks, traffic information networks, medical knowledge networks, etc. And if we want to avoid spending our lives administrating these networks self-configuring, self-managing, self-healing technologies for networks will be needed. In other words we could say that these “networks” should be alive. And this is why BT Labs are looking for inspiration from nature.
On the other hand, what is transported and managed in these networks is not anymore just an electric signal. Today what the telecom industry is interested in managing is knowledge and people. This is a completely new challenge for this industry to address. Some people at the research labs believe that nature inspired systems are especially suitable for this type of complex, human-related networks.

## OLD CHALLENGES

Even if the telecommunication industry is changing into more global information technologies, it still has to manage and provide a quality service when exploiting its telecommunications network. What we call here the old challenges, are problems oriented around the physical operations on the infrastructure. The general idea behind it, is to find fast and efficient solutions for the continuous dynamic changes of the networks in terms of issues ranging from topology to demands for services.
Five years ago (2000) British Telecom research had a large number of projects active in this area. Most of them focused on the optimisation of some particular aspect of their networks. Unsurprisingly most of the nature-inspired solutions were of the evolutionary type, since it was know that these techniques are quite good for optimisation purposes. In the following, we present some of the challenges addressed by these projects and the proposed solutions.

### *Network design and planning*

The optimal design of telecommunications networks infrastructures demands considerations of many complex factors such as type, number and position of components and cable paths – consistent and cost-effective solution.
British Telecom research showed that Genetic Algorithms can generate different network configurations and evaluate them rapidly to arrive to an optimal or near-optimal solution [1].

Another problem tackled by the industry is how to respond to rapid network growth, as for instance for the dial-up IP access network. In this framework BT developed an approach in which a genetic algorithm is employed to produce optimised sets of planning rules that can be used by network planners and designers to aid in the task of growing telecommunications networks. The optimisation takes into account basically constraints of cost and quality of service. [2] [3]

### *Network traffic management*

Telecommunication networks are interconnected by routers and networks protocols must find a path to connect them. This process is known as routing. The usual approach is to estimate the shortest path using a heuristic. BT proposed to combine this with a genetic algorithm in order to find solutions, which lead to less congested nodes and links and a better utilisation of network resources. [4]

Discontinuous communication or limited bandwidth networks
When facing discontinuous communication or a limited bandwidth network then it is not possible to have heavy and/or continuous exchange of data. In this case, a natural idea is to instead of moving the data around to move the software. For this problem BT proposed an insect inspired approach. The idea is that mobile software agents will perform local

processing of data as opposed to remote access. But to execute remotely, mobile agents move (as insects) to a machine running a mobile agent server, which provides an interface to the underlying host machine. [5]

### *Perspectives for nature inspired solutions of the "old challenges"*

British Telecom research laboratories are not only interested in adapting solutions (e.g. existing algorithms) to the industrial problems, they also look to improve them using their knowledge of the limitation based on confrontation with real world applications. In this line BT has proposed several fundamental research perspectives for genetic (evolutionary) computation, among them the genotype-phenotype mappings and the introduction of economics into the evolution.
The idea behind the *genotype-phenotype mappings* is to separate the coding (genes - genotype) and the actual resulting organism (phenotype), which is actually the result of a complex developmental process played out as the genetic information is interpreted.
The idea of introducing economics into evolution is to complete the genetic-inspired view in which interaction occurs only via exchange of agent characteristics encoded as genes, plus measures of success. And an *economic-inspired* view has agent adaptation driven by changes in prices and supply and demand.

## NEW CHALLENGES

Today the telecommunication industry is facing radical changes. In fact, it is considered the world's fastest-moving business sector. Based on what is done at British Telecom laboratories we can split the "new challenges" into two large groups: networks everywhere and knowledge networks.

### *Networks everywhere*

As the cost of the hardware falls, the number of communication technologies increases (exemplified by wireless networking such as Wi-Fi, Bluetooth or 3G). All sorts of components and devices will communicate with one another in order to provide useful applications and services. This will lead to a situation in which there will be all sort of networks, literally everywhere. The industry is already strongly interested in emerging issues such as Web Services, GRID computing, and Peer-to-Peer (P2P) computing.
The increase in number of networks (and nodes) as well as the complexity of them is such that they are becoming unmanageable. We will be soon (or are already today) not able to manage all the networks with which we daily interact. All of the major Information Technologies companies have programs seeking to address these issues. In this context British Telecom follows IBM's "Autonomic Computing" initiative. It is a "nature-inspired" approach in that it draws inspiration from the human autonomic nervous system where many functions, such as breathing or heart rate, are regulated by the system itself without conscious effort. By analogy, the idea is to create systems that are more "autonomic" (self-managing and resilient) in the following ways:

- **Self-configuring:** adaptation to changes such as new nodes appearance/disappearance;
- **Self-optimising:** tuning resources and load balancing;
- **Self-protecting:** guard against damage from attacks or failures;
- **Self-healing:** recovery from, or work around, failed components.

In this sense British Telecom has today (2005) several projects, which tackle real world problems and exhibit an autonomic behaviour.

**Channel (resource) allocation:** The allocation of channels in a mobile telephone network is one example of a range of problems involving allocating resources in geographically or logically dispersed systems. This is usually solved by applying a centralised optimisation, which implies a good knowledge (and model) of the networks at all times. BT proposed to decentralize the configuration by looking at how cells (in the fruit fly) are able to produce a highly detailed and accurate macro-structure (the adult form) without any global knowledge. The result is a self-configuring network. More importantly it brings with it the ability to continue to function well even in a network which constantly changes; by losing or gaining nodes or where nodes may move and where accurate up-to-date information about the overall network is not available. In this sense it is also self-healing. Another advantage of a decentralized approach is that scaling is straight forward. [6]

**Security:** With the increase of the number of networks security has to become automatic, in other words the networks have to be able to defend themselves. BT has several nature-inspired projects in this area.

BT developed a biologically-inspired form of inhibitory signalling between hosts that could be used to detect suspicious global activity patterns. This approach is decentralized, which is desirable for reasons of scalability. The idea is that individual devices compute an "alert level" on the basis of locally detectable network activity, then exchange beacon signals with other nodes, which are effectively a digest of security-relevant information (i.e. the alert level, but also identity, internal state etc.). The collected beacons are then used by every member device to update its own alert level, which creates a feedback loop allowing the community of peers to rapidly converge toward a state reflective of the globally perceived threat level. [7]
Another BT project focuses on trying to protect the networks from unknown viruses. In fact, traditionally viruses are detected using their signatures, which means that a copy of the virus is needed to detect them. So, BT proposed to look at the network as a being that is sick (because of a virus). In order to heal the problem they propose to look rather at the global symptoms than trying to find what exact virus is attacking, and then eliminate the viral spread as fast as possible.

**Service provision:** In today's continually growing and changing networks external human control becomes untenable, especially for positioning the right active software in the right place at the right time. For this particular problem BT developed a bacterium inspired software distribution algorithm. The hardware that the software runs on can be viewed by analogy as the bacteria and the associated genetic diversity is created in at least two ways, namely mutation and plasmid migration. Mutation involves the random alteration of just one value in a single rule. Plasmid migration involves genes from healthy individuals being shed or replicated into the environment and subsequently being absorbed into the genetic material of less healthy individuals. This automatically leads to good load balancing and effective distribution of new software. What is particularly interesting with this approach is that while external management is not required it supports manual intervention. Active software can be manually placed on the network, with associated policies for its use; its adoption and proliferation will depend on user behaviour and this initial placement. [8]

## *Knowledge and Social networks*

Even if the management of networks is still in the heart of the telecom business, there is more and more interest in what circulates in the networks and to whom it is being delivered. The new vision is that what circulates is not just an electric signal, but information, knowledge; and that at the reception we have not just phones, but actually users, social beings. The new challenge, with respect to traditional problems, is that the knowledge is distributed over a network, there is much more complex information circulating and the actors are distributed all over. This change of vision is clearly the biggest change of the telecommunication industry and responding to the new challenges is vital.
In the new position as a global ICT company, BT conducts research projects regarding knowledge management, intelligent systems and interaction between the digital world and the users.
At the moment when writing this document BT has not any nature inspired systems, in a narrow sense (i.e. natural but not human), which would face any of these problems, although BT believes that the use of a nature metaphor does have important contributions to offer in the future. Now, if we broaden the definition of 'nature-inspired' to consider that humans' social organisations and human abilities are natural inspirations, then there are, already today, some projects at BT addressing these issues.

**Improving online directories:** While online directories within many large organisations have made it easier to find co-workers' phone numbers, finding and contacting the right person can still be a challenge. Inspired by the "social" idea that we all live in a small world, BT has developed a phone directory, which uses peoples' social networks to help them make quicker connections. In fact, social communities exhibit a "small world" phenomenon in which everyone is connected via a short chain of acquaintances. Then they by determining the proximity in the social community they rank the responses of a search result. And it seems that this increases tremendously the chances of obtaining the right number at the top of the list. Other "social" ideas have been tested, for example grouping and ranking them according to various predefined criteria, such as their organisational unit or geographical location. [9]

**Multimedia interaction:** Due to the accessibility of today's networks, more and more information is being exchanged. And more and more this information is becoming complex and difficult to handle. One example of this evolution is the strong presence in today's virtual world of multimedia. But, how to transmit this information over the network in an efficient way? How to interact? How to perform search with this type of data? BT's approach is to get inspired by how the human (and the human eye) solve these problems. The idea is that people very quickly and easily can find out what is important, for instance on an image; and this without the use of any complicated algorithm. BT developed a heuristic, inspired by human attention, which finds by randomly sampling what is important on an image (or visual content). Having extracted this, they are able to improve transmission over a network, by compressing the less interesting parts more than the areas worthy of attention. Also, based on this approach it is possible to propose more "interesting" (from a human point of view) interaction tools, for instance search engines. [10]

## CHALLENGES NOT NATURE INSPIRED YET…

Another strong direction pursued by BT in relation to networks is intelligent systems. In fact, they see the networks as an infrastructure upon which services can be built. Due to the increase of the complexity and the number of the networks and their pervasive presence, the new technologies must be smart. Until today this challenge has been addressed in BT based on Soft Computing. These technologies can be seen, already, as nature inspired in a broad sense. But what is most important, they represent a starting runway.
Around this axis we can say that BT is concerned with four research themes [11]:

- **Ontologies and Semantics:** BT is greatly interested in an emerging type of knowledge network, the so-called 'Semantic Web'. The idea being to provide an Internet which consists of data and resources that can be logically integrated and manipulated much more easily than is the case with the original infrastructure. And one of the ideas to achieve this is a mechanism that enables the providers to semantically structure their information. This last approach has been translated in the development, by the research community, of the OWL language. This mechanism can be seen as crucial for semantic communication and interaction, and therefore is a keystone for other technologies presented here.
- **Agents:** Systems integration is an expensive and problematic part of developing any computer network; it is also an expensive overhead on the running costs of any real deployment. And not only this, software will move around the network and will need to act in different environments. Autonomous agents, which could be easily inspired from nature, form one BT approach to producing software that is able to cope with changes. Moreover if we want these agents to interact in an open world as it is, for instance the Internet, then it is clear that they will need some semantic tools as found in the semantic web.
- **Natural Human Interfaces:** Interfaces are the entry point, for humans, to the networks. Again because of the number of networks, naturalness of interaction will be needed. Humans express the same meaning in many different ways, for instance by spoken words or with a gesture. So the search for new ways to interact with machines, playing to the strengths of human psychology and physiology, constitutes a strong interest for BT in 2005.
- **Data Mining and Machine Learning:** The networks not only produce a lot of data they also are meant to transport data. But, can we extract any knowledge of all this distributed data? The answer is another key challenge for BT research. By using machine learning the telecom industry could learn about their users (e.g. what they like, their habits, etc.). This knowledge could be extracted and provided to some decision makers inside British Telecom. But also the system could learn directly from the users and adapt to their behaviour without any external intervention. For this difficult problem it could be interesting to get inspired from nature where often we observe delocalized (or global) learning.

## FUNDAMENTAL INSPIRATIONS

British Telecom sponsors not only applied technology innovation, but also some inspirational fundamental research. For instance, they believe that the following biological fields if understood could lead to fantastic new technologies, just by getting inspired from them.

**Morphogenesis:** The development of a multicellular creature from a fertilized egg is a spectacular example of creating organised complexity. The egg is a single cell with little "pattern" while the resulting adult organism consists of up to $10^{13}$ cells of many varieties and is exquisitely ordered, sculpted and patterned. The management of large, distributed, dynamic, interacting systems and the creation and elaboration of ever greater complexity are vital goals for future computational systems. BT tries to find, what lessons can be learnt from nature's successes and how might those lessons be applied to telecommunications problems? [12]

**Genetic Regulatory Networks:** Genetic networks are only beginning to be understood, from the biological point of view. Nevertheless British Telecom believes that what is already known could be extremely useful as source of inspiration. In fact, genes can be viewed as nodes in a network, with input being proteins and outputs being the level of gene expression. And what is particularly interesting is that the very simple genetic functions (coding) determine the complex cellular behavior, in a very stable and efficient manner. The goal of BT is to further develop and refine computational models and to apply them to a concrete telecommunications problem. [13]

## CONCLUSIONS

The telecommunication business has dramatically changed in the last years. Its centre of interest has shifted for that the management of static telecommunication infrastructure to mobile and pervasive knowledge networks. Two new challenges appear: First, since networks are going to be everywhere in a large number, how to automatically manage (self-optimise, self-configure, self-protect etc.) them? Second, the focus has moved away from how the signals are transported towards the information or services these signals may deliver. The new challenge is then how to have intelligent and adaptive Knowledge and Social networks.
BT seeks natural inspiration to answer these questions. They have a strong belief that they will find something, but we should not forget that the inspiration is not a goal in itself, and nor are the derived models. For industry the technology and its commercial opportunities are the centre!

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