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Biologically inspired networking: A solution over the challenges of ordinary networking

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Abstract

The steadily growing speed of technological development, computer networks are becoming increasingly complex. At the same time, they must fulfill ever higher requirements in terms of performance, scale, robustness etc. while minimizing their use of resources and adapting to dynamics. The communication between network embedded systems has become a major research domain in the communication network area. Wireless sensor network (WSN) and sensor/actuator network (SANET) build of huge amounts of interacting nodes build the basis for this research. From very long time, nature and biology have inspired new technologies. In computer networking and specifically wireless networks, this field of bio-inspired networking is new and becomes very popular with the emergent of new types of networks with intelligent and autonomous mobiles and/or base stations. Bio Inspired networking has fostered new developments in networking, especially in the most challenging domains such as handling large scale networks, their dynamic nature, resource constraints, heterogeneity, unattended operation, and robustness.

1. Introduction

Our computer networks [1] are increasingly facing some challenges as they grow larger in size, but are yet to be able to achieve the same level of robustness and adaptability. The term bio-inspired has been introduced to demonstrate the strong relation between a particular system and algorithm, which has been proposed to solve a specific problem, and a biological system, which follows a similar procedure or has similar capabilities. Many methods and techniques are really bio-inspired as they follow principles that have been studied in nature and that promise positive effects if applied to technical systems. We have witnessed unprecedented growth of the Internet. Moreover, the Internet continues to evolve at a rapid pace in order to utilize the latest technological advances and meet new usage demands. It has been a great research challenge to find an effective mean to influence its future and to address a number of important issues facing the Internet today, such as overall system security, routing scalability [2], effective mobility support for large numbers of moving components and the various demands put on the network by the ever-increasing number of new applications and devices.

A complicated, strictly organized internal structure is necessary for any system to exhibit robust external behavior. There is an inherent trade-off between structural simplicity and robustness. Both the human body and the Internet have a complex, strictly organized internal structure. The human body has many different organs and physiological systems, each of which serves a specific purpose. A kidney cannot serve as a lung not vice versa. The Internet also contains a number of specialized devices. At its core there are high-speed routers, which single-mindedly forward data in a highly optimized manner. At the edges of the network there is a diverse array of application-oriented devices, such as laptop computers and cellular phones. A high-speed router would be no more helpful in reading our e-mail as a kidney would be no more helpful in oxygenating our blood.

Technical challenges include the management of thousands and millions of inter-networking devices that have to be organized using scare resources and disruptive communication channels [3]. In spite of

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these limitations, the networking community is developing astonishing technical solutions, in many cases inspired by self- organization mechanisms inherently existing in Nature. Basically, the following application domains of bio-inspired solutions to problems related to computing and communications can be distinguished.

- **Bio-inspired computing:** represents a class of algorithms focusing on efficient computing. E.g. in optimization processes and pattern recognition
- **Bio-inspired systems:** rely on system architectures for massively distributed and collaborative systems. E.g. in distributed sensing and exploration
- **Bio-inspired networking:** is a class of strategies for efficient and scalable networking under uncertain conditions. E.g. in delay tolerant networking [4].

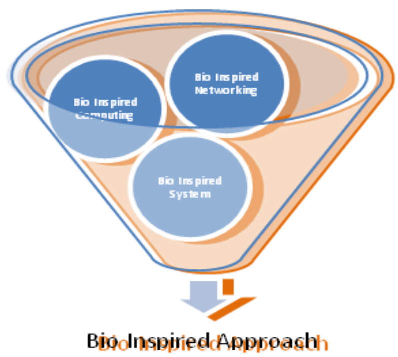


Fig: 1. Bio-Inspired Approach

2.0 Challenges of Networking

2.1. Handling Large Scale networks

One of the main challenges is related to the sheer size exhibited by the networking systems, which connect huge numbers of users and devices For example, Wireless Sensor Networks[5] (WSNs) are composed of a large number, e.g., in numbers ranging between few hundred to several hundred thousands, of low-end sensor nodes. The direct consequence of such large scales is the huge amount of traffic load to be incurred over the network. This could easily exceed the network capacity, and hence, hamper the communication reliability due to packet losses by both collisions in the local wireless channel as well as congestion along the path from the event field towards the sink. As the network scale expands, the number of possible paths, and hence, the search space for the optimal route also drastically enlarges. The maintenance of routing tables and the amount of traffic for table updates also increase. Hence, networking mechanisms must be scalable and adaptive to variations in the network size. Fortunately, there exist many biological systems that inspire the design of effective communication solutions for large scale networks. For example, Ant Colony Optimization (ACO) techniques that are based on optimizing global behavior in solving complex tasks through individual local means provide efficient routing mechanisms for large-scale mobile ad hoc networks [6].

2.2. Network dynamics

The control of complex networks is of paramount importance in areas as diverse as ecosystem management, emergency response and cell reprogramming. A fundamental property of networks is that perturbations to one node can affect other nodes, potentially causing the entire system to change behavior or fail. Here we show that it is possible to exploit the same principle to control network behavior. Our approach accounts for the nonlinear dynamics inherent to real systems, and allows bringing the system to a desired target state even when this state is not directly accessible due to constraints that limit allowed interventions. The existing and the envisioned networking architectures are highly dynamic in terms of node behaviors, traffic and bandwidth demand patterns, channel and network conditions. The channel conditions and link qualities are highly dynamic due to mobility of the nodes, and environmental variations as a result of this movement. This dynamic nature can be seen in the target tracking applications of sensor networks, where the amount of traffic created by the sensor nodes may drastically increase at the time of detection and may decay with time. The biological systems and processes are known to be capable of adapting themselves to varying circumstances towards the survival. For example, Artificial Immune System [7] (AIS), inspired by the principles and processes of the mammalian immune system, efficiently detects variations in the dynamic environment or deviations from the expected system patterns

2.3. Resource constraints

As the communication technologies evolve, demands posed upon the networks also drastically increase in terms of the set of available services, service quality including required bandwidth capacity, and network lifetime. For example, the current Internet can no longer respond to every demand as its capacity is almost exceeded by the total traffic created, which lays a basis for the development of next generation Internet [8].At the same time, with the increased demand from wireless networking, fixed spectrum assignment-based traditional wireless communications has become insufficient in accommodating a wide range of radio communication requests. On the other hand, some next generation networking architectures, e.g., Interplanetary Internet [9], intrinsically possess resource constraints due to their physical and structural limitations. More specifically, for the networks terms of energy and communication resources, e.g., WSNs [5], Mobile Ad Hoc Networks flies [6], nano scale and molecular communication networks [10], these limitations directly bound their performance and mandate for intelligent resource allocation mechanisms. The biological systems yet again help researchers by providing pointers for mechanisms and solution approaches which address the trade-off between the high demand and limited supply of resources. For example, in the foraging process [11], ants use their individual limited re-sources towards optimizing the global behavior of colonies in order to find food source in a cost-effective way. The behavior of ant colonies in foraging process inspires many resource-efficient networking techniques. Furthermore, cellular signaling networks and their artificial counterpart represent and capture the dynamics of interactions contributing to the main function a living cell. Hence, they might also enlighten important avenues to obtain efficient communication techniques for resource constrained nano scale and molecular communication network

2.4. Heterogeneous architecture

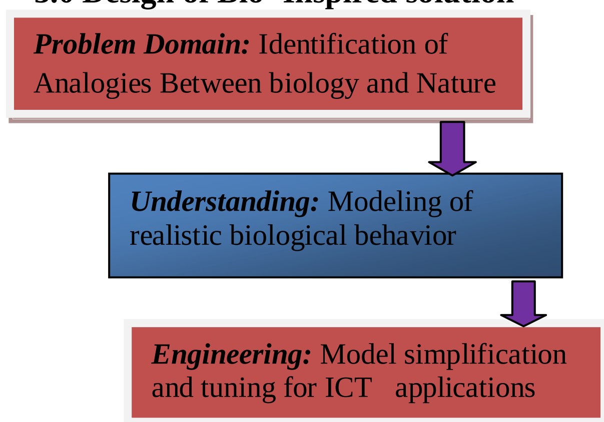
Next generation communication systems are envisioned to be composed of a vast class of communicating devices differing in their communication/storage/ processing capabilities, ranging from simple sensors to mobile vehicles equipped with broadband wireless access devices. For example, internet of things is defined as a vision of network of objects which extends the Internet capabilities into our daily lives transforming our immediate environment into a large-scale wireless networks of uniquely identifiable objects, Cognitive radio networks, Wireless mesh networks and WiMAX, Sensor Network and Vehicular AdHoc Network(VANET). Such heterogeneity and asymmetry in terms of capabilities, communication devices and techniques need to be understood, modeled and effectively managed. Different levels of heterogeneity are also observed in biological systems. For example, in many biological organisms [12], despite external disturbances, a stable internal state is maintained through collaborative effort of heterogeneous set of subsystems and mechanisms, e.g., nervous system, immune system. On the other hand, insect colonies are composed of individuals with different capabilities and abilities to respond to a certain environmental stimuli. Despite this inherent heterogeneity, colonies can globally optimize the task allocation and selection processes via their collective intelligence.

2.5. Need for robustness and autonomous operation solving networks

Wireless adhoc networks, Wireless Sensor Networks (WSNs) can function effectively without any help from a centralized unit. But communication networks are subject to failure either by device malfunction, e.g., nodes in a certain area may run out of battery in sensor networks, or misuse of their capacity, e.g., overloading the network may cause heavy congestion blocking the connections. It is clear that networks must be capable of re-organizing and healing themselves to be able to resume their operation. Hence, the existing and next generation information networks must have the capabilities of self-organization, self-evolution and survivability. Inherent features of many biological systems stand as promising solutions for these challenges.

- Autonomous behavior of artificial immune systems [13] inspires the design of effective algorithms for unattended and autonomous communication in sensor network.

3.0 Design of Bio- Inspired solution



These primary principles of investigation and exploiting biological inspirations are depicted in figure .First, analogies between biological and technical systems such as computing and networking systems must be identified. It is especially necessary that all the biological principles and their governing dynamics are understood properly, which is often not yet the case in biology. Secondly, models that capture the biological behavior must be created to be later used to develop the technical solution. The translation from biological models to the model describing bio-inspired technical systems is a pure engineering step. Finally, the model must be simplified and tuned for the technical application.

Phenomena of Bio Inspired Networking

S.No.	Biological principle	Application fields in networking
1	Swarm Intelligence and Social Insects	distributed search and optimization; routing in computer networks, especially in MANETs, WSNs, and overlay networks; task and resource allocation
2	Firefly Synchronization	robust and fully distributed clock synchronization
	Activator-Inhibitor Systems	(self-) organization of autonomous systems; distributed coordination; continuous adaptation of system parameters in highly dynamic environments
3	Artificial Immune System	network security; anomaly and misbehavior detection
4	Epidemic Spreading	content distribution in computer networks (e.g. in DTNs); overlay networks; analysis of worm and virus spreading in the Internet
5	Cellular Signaling Networks	coordination and control in massively distributed systems; programming of network-centric operating sensor and actor networks

Table: 1. Categorization of Biological Phenomena and Networking Algorithms Mimicking These Concepts

4.0 Conclusion

In this paper, the common fundamental networking challenges and the current status of research efforts to address them from the perspective of bio-inspired networking is captured. As for the nature, however, they could have great potential to assist with better and more efficient network management in telecomm networks, particularly for the future dynamic non-centralized heterogeneous environment.

Through the existing research results, it has been shown that the inspiration from biology is indeed a powerful source of innovative network design. Despite the considerable amount of ongoing research, projects, the bio-inspired networking research community is quite young, and there still remain significantly challenging tasks for the research community to address for the realization of many existing and most of the emerging networking architectures.

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