Cognitive Network Ecosystems and Biological Symbiosis

Report for an exchange visit funded by PerAda

Visitor:
Dr. Tinku Rasheed
Network & Security Solutions for Pervasive Computing Systems (iNSPIRE)
CREATE-NET Research Center
Trento, Italy

Host:
Prof. Emma Hart
School of Computing
Napier University
Edinburgh, U.K.

Context

The aim of the research visit is to enlarge the research collaboration and exchange between the Center of Emergent Computing, at Napier University and the pervasive group at Create-Net research centre in the area of 'applying biological symbiosis principles to communication and networking systems'. As part of this effort, the two centres are jointly investigating coexistence issues within a multitude of cognitive wireless networks seen as an ecosystem; where they are currently focussing on a new and specific type of cognitive wireless networks; termed as *cognitive symbiotic networks*. The principle objective of this interdisciplinary research visit is to develop a unified framework for cognitive networking ecosystems synthesized from a novel multi-disciplinary approach incorporating biological modelling, game-theoretic approaches etc.

Discussions

The discussions during the research visit were triggered with a joint meeting with Prof. Hart and the researchers from University of Abertay, Dundee; Prof. James Bown and Prof. Ruth Falconer, who are experts in the field of biological symbiosis, particularly for their research on fungal colonies and plant behaviours. During this meeting, interesting aspects regarding the behaviour of cognitive networks with that of biological species were compared and several arguments were addressed. The broad conclusion from the interactions was that symbiosis in organisms can have several similarities with the behaviour of coexisting cognitive networking systems. It is very important to understand the resources that the cognitive networks need to exchange effectively to represent a coexisting behaviour and later these resource exchanges can be mapped to the symbiotic behaviour in organisms to develop adequate models for cognitive network ecosystems.

Another interesting discussion during the visit was related to the application of immune system behaviour in wireless network monitoring, particularly for distributed monitoring in wireless mesh networks. Initial discussions with Prof. Hart was helpful to understand the immune system behaviour and the innate immune-inspired model which can be adapted to develop agent-based models for distributed monitoring of wireless mesh networks. Dr. Rasheed is following up on these discussions and is currently developing a soft distributed monitoring framework to be assessed in a real system.

A research talk was given to the members of the centre, mainly focussed on Dr. Rasheed's current research at CREATE-NET. The talk drew some interest and some subsequent discussions were carried out, notable of which was the interaction with Prof. Al-Dubai. We discussed about energy efficiency of wireless communication systems and possible future collaborations in this direction.

Symbiotic Cognitive Networks: A Proposal

Cognitive radio is a paradigm for wireless communications in which either a network or a device can change its transmission or reception parameters (power, frequency etc.) to communicate efficiently avoiding interference with adjacent networks. This alteration of parameters is based on the active monitoring of several factors in the external and internal radio environment, such as radio frequency spectrum, user behaviour and network status. Cognitive networks are characterized by flexible network architectures exploiting the capabilities of cognitive radios[1] and have the potential to drive significant innovations.

As the global telecommunication industry is gearing itself towards the implementation of wireless networks which are autonomously managed, we can foresee a plethora of flexible and heterogeneous wireless networks including: wide-area terrestrial infrastructure networks, sensor networks, femto-cellular networks, mesh networks, self-organizing ad hoc networks which will need to coexist and cooperate in a global environment. Figure 1 depicts a typical scenario; a single telecom operator leases spectrum in a certain range - within this spectrum, a number of individual (and heterogeneous) networks (CN1, CN2,...) are required to operate without causing interference to each other. In order to minimize interference, each network has two choices:

- Operate at a unique frequency (depicted by the vertical bars on the right hand graph)
- Operate at low power which limits interference with other networks (depicted by the horizontal bar).

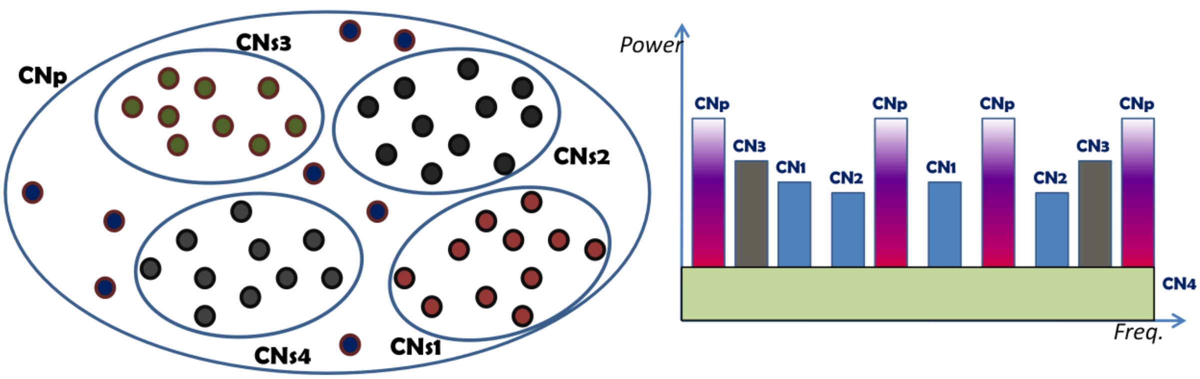

Figure 1: A system of networks composed of heterogeneous physical sub-networks

Therefore, for the global system to function, each of the networks must cooperate and/or collaborate by sharing and/or adapting its resources. Cognitive radio offers the potential to endow the networks with the ability to adapt such that a scalable system of networks can be created, optimized in terms of energy efficiency and resource conservation. However, its use to date has been mainly limited to frequency agility, i.e in selecting the best radio access technologies and frequencies at which to operate. In order to fully exploit its potential, we propose to exploit the adaptive capabilities of cognitive radio to create systems of networks. A major challenge is to quantify the degree of interaction between the heterogeneous sub-networks and to enable these sub-networks to operate

[1] C. Fortuna and M. Mohorcic. Trends in the development of communication networks: Cognitive networks. Computer Networks, 2009.

efficiently without compromising their own resources. Moreover, a unified approach to the design of cognitive networks is necessary to characterize the scale at which the cognitive network interactions can grow and flourish, in a global system of networks.

While designing systems of cooperating networks may be challenging for engineers, it is a problem which has been neatly solved in nature by evolution, which enables stable eco-systems to exist in which multiple species either co-exist – that is, live in separate niches which do not overlap, or exist in symbiotic relationships, a term which was first coined in 1879 to describe 'the living together of unlike organisms'. We propose that co-existence within natural ecosystems has an obvious analogy to property (1) listed above where as symbiotic relationships map neatly to property (2). In the remainder of the paper we outline the main principles of these biological relationships and describe a mapping between the concept of an ecosystem of cognitive radios and biological systems. We propose that by looking in detail at two biological systems - the immune system and fungal communities - we can develop novel techniques for implementing the cognitive network paradigm.

Symbiotic relationships in nature occur in three forms; commensal, mutualistic and parasitic. The first two are of relevance to our argument. In commensal symbiotic relationships one organism reaps the benefit of another, while the other is not significantly harmed. The mammalian immune system provides an excellent example of such a relationship in which some species of bacteria successfully colonize our body and provide us with essential function without which we could not survive, such as stimulation of the gut, immune system development, rejection of pathogenic bacteria, and contributions to our nutrient supply.

In mutualistic relationships, both the species involved in the relationship benefit from each other. Such relationships are observed between fungi and plants; fungi invade or live amongst the secondary roots of the plant - this benefits the plant which achieves a more efficient mineral uptake and also the fungi which benefit from the sugars translocated to the root by the plant. This relationship is also interesting from the perspective of the plant which could maintain its own mineral supply, but chooses to leave this to the fungi in order to optimize its resources elsewhere. Co-existence relationships are also observed in fungal communities; for examples different colonies can co-exist by sharing resource yet maintain exclusive areas. We propose that by modelling and abstracting these biological processes, it may be possible to construct cognitive networks which can collectively exist within an eco-system that is globally optimal in terms of efficiency and usage of resource. A mapping between the two paradigms is shown in table 1.

Cognitive Network	Example	Biological System
Devices	Laptop, phone	Organism
Network	Wireless network	Species
Network of networks	Spectrum licensed by single operator	Ecosystem

Table 1: mapping between biological and cognitive networks

We propose to investigate the possibility of creating scalable, adaptive ecosystems of networks by looking to biology. In summary, the ultimate goals of our work are to explore theoretical models and abstract mechanisms of symbiosis to identify and model the interaction patterns of symbiotic relationships in light of the requirements stemming from future generation wireless networks; to quantify the amount of resources required for specific operations in coexisting networks, thereby conceiving an overall eco-footprint model for cognitive networks via adapted metrics derived from the proposed mapping; and to realize a unified framework for symbiotic cognitive networking synthesized from a novel multidisciplinary scientific approach.