Interdisciplinary issues for the management of next generation autonomic wireless systems: nature-inspired techniques and organic computing

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Abstract: Next generation communication systems have become a hot research issue in these last few years. For an efficient management of these networks, multidisciplinary knowledge and cooperation between different research fields is important. In particular, the next generation of wireless systems needs to satisfy some self-properties such as self-describing, self-organising, self-managing, self-configuring, self-optimising, self-monitoring, self-adapting and self-healing. In order to provide these features traditional approaches cannot be employed, owing to the computing complexity involved, so new solutions must be considered. The most suitable techniques to solve the above-mentioned issues is certainly organic computing and nature inspired techniques. Therefore, the main goal of our work is to provide a description of the principal characteristics of these new kinds of network and an overview in the various nature-inspired and organic computing techniques such as the neural network, molecular computing, Cellular Automata (CA), Genetic Algorithms (GAs), epidemic propagation strategies and finally, Swarm Intelligence (SI).

Keywords: nature-inspire techniques; next generation wireless networks; self-properties; organic computing.

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1 Introduction

There is an increasingly widespread agreement within the community that biologically-inspired solutions are likely to play a key role in autonomic computing, network management and communication (see e.g. Babaouglu et al. (2006)). Indeed, biologically complex systems tend to exploit fully decentralised and uncoupled coordination models exploiting cooperation mechanism able to reach specific targets. This translates into desirable properties such as *scalability*, *adaptability* and *efficient computation* to change conditions and dynamic scenarios, and *robustness* to partial failure and/or hostile disruption of normal activity.

Specifically, the next generation network needs to present the so-called self-properties that consist in the capability of self-describing, self-organising, self-managing, self-configuring, self-optimising, self-monitoring, self-adapting and self-healing. To satisfy these properties the next communication systems management needs to be distributed and decentralised in order to allow communication systems based on different technologies.

Although, pervasive computing is generally regarded as distinct from networking, there is a significant convergence. A network is essentially a sensorised system which can observe its own low-level activities and constraints. This may be combined with higher-level contextual information about users, services and applications within a framework of uncertain reasoning.

The system collects information from a variety of sources including traditional network sensors and reporting streams but also including higher-level device and user context. These are analysed to build a model of the evolving situation faced by the network and its services with this model used as basis for adaptation decisions. These decisions are actuated through the network and will potentially be reported to users or administrators. The impact of the decisions can be then collected to inform the next control cycle.

The context in which these algorithms will have to operate ranges from classical packet-switching networks, in which routers have to act and react locally to different network traffic behaviours, to sensor and ad hoc networks that have to organise themselves in order to operate (Culler et al., 2004; Ramanathan and Redi, 2002), and to cognitive networks that include functionalities of sensing and environment (Thomas et al., 2005), context and situation consciousness and that impose a distributed paradigm of communication (generalised ad hoc networks). Moreover, these communication paradigm and technologies can operate Peer-to-Peer (P2P) and overlay networks with high scalability issues (Theotokis and Spinellis, 2004), mobility issues and very dynamic context. New algorithms that are currently proposed with a very specific kind of communication system in mind and addressing a specific technology cannot be suitable to operate in other systems. This determines few interoperability properties and a limited context of use. It would be of great interest to define general weak models of communications systems so that any algorithm that works for these models can be used in several real communication systems of different classes. Somewhat orthogonally to these two approaches, a designer needs to understand how a given stimulus will affect an algorithm's behaviour. Adaptation is not an excuse for incorrectness: one wants an algorithm's behavioural 'envelope' to be well-defined, regardless of the possible conditions that occur in the network (Dobson, 2006). Allowing free adaptation within an envelope provides a more precise notion of reliable behaviour, while placing clear limits on the degree to which self-management is allowed to weaken (or compromise) service guarantees.

The reviewed systems use approximate optimisation algorithms to solve optimal path problems. The algorithms used are approximated optimisation algorithms as they only attempt to provide a good enough solution to a problem in reasonable time, whereas, optimal algorithms strive for convergence on a global optimal solution.

The main goal of this paper is to provide an overview about a new generation of wireless systems: in particular, the most important features that this next generation should satisfy such as scalability, adaptability, Quality of Service (QoS) support, security and so on, will be described. Moreover, an overview on the most suitable techniques to solve the above-mentioned issues will be provided: organic and nature-inspired computing. The most important organic computing techniques: neural network, molecular computing, Cellular Automata (CA), Genetic Algorithms (GAs), epidemic strategies and finally, Swarm Intelligence (SI), are described in detail.

This paper is organised as follows: the novel generation of wireless systems with their main characteristics are presented in Section 2; Section 3 presents a brief overview of the most famous organic computing techniques applied in the Information and Communication Technology (ICT) field and finally, conclusions are summarised in Section 4.

2 Organic computing

Organic computing is a new discipline based on biological processes using these principles in the computer science areas. These mechanisms provide systems able to adapt themselves dynamically to the scenario around them. Generally, they are denoted *self-properties*, like *self-improvement*, *self-healing*, *self-organisation* or *self-protection*.

An important activity of these systems is observing of the environment to understand how they can adapt themselves to it. Among the main advantages of self-organised systems are: flexibility, robustness against (partial) failures and self-optimising and adaptability to user needs. In the following subsections some of the most famous organic computing techniques and paradigms are presented.

2.1 Neural networks

The history of neural networks shows the interplay among biological experimentation, modelling and computer hardware implementation. 'McCulloch and Pitts (1943) designed what is generally regarded as the first neural network: they recognized that combining many simple neurons into neural systems was the source of increased computational power'. In 1949, Hebb designed the first learning law for Artificial Neural Network (ANN) (Hebb, 1949); an expanded form of Hebb learning is presented in McClelland and Rumelhart (1988), where the units that are simultaneously off also reinforce the weight on the connection between them. Rosenblatt (1958) introduced a large class of ANN called perceptrons, leading to enthusiastic claims, however, the mathematical proof of the convergence of iterative learning under suitable assumptions was followed by a demonstration of the limitations regarding what the perceptron type of net can learn (Minsky and Papert, 2003). In the 1970s and in the 1980s, many works dealt with associative memory neural nets, subsequently applied to speech recognition, as the work of Kohonen (1972), who developed self-organising feature maps that use a topological structure for the cluster units; the propagation of information about errors at the output units back to the hidden units (back-propagation) was also investigated. In Hopfield (1982) different ANN are illustrated, based on fixed weights and adaptive activations. Different applications of ANN in the telecommunications community are available in the literature; in Kumar and Venkataram (2003) the authors proposed a multicast routing algorithm based on Neural Network (NN-based) in order to obtaining an efficient multicast tree. A Kohonen's self-organising-map ANN was used for clustering and a Hopfield neural network model was introduced for the construction of a reliable multicast tree, with a minimum number of links which pass through the nodes that belong to the centre cluster. Neural networks are also employed to manage packet scheduling in packet switched networks. In Badia et al. (2004) the possibility of self-organisation for packet-switched networks at the scheduling management level is proposed. In Tang and Olli (2002) a traffic shaping for optimal system utilisation in telecommunication applications is introduced. The method uses the Self-Organising Map and a Decoding method (called SOM-D) to construct an adaptive resource management for certain systems. Neural nets are also applied for paths construction: in Wang and Weissler (1995) the problem of how to determine the optimal paths to route the message between nodes making up the network. The optimal path then becomes the path in which the total cost of routing a message between a source and destination node is minimised. The ANN have many possible applications and useful characteristics for the analysed problems: a structure based on simply units (the neurons); capacity to extract common characteristics by the input data and capacity to divide the input features on the basis of the common characteristics. Self-organisation is a great peculiarity of the ANN and different proposed ideas in the literature can take advantage of that: in Vicente et al. (2005) a self-organising routing protocol for ad hoc networks, called the NEUron Routing ALgorithm is proposed (NEURAL). It was designed taking into account the learning and self-organising abilities of the brain. The design of NEURAL is based on three main phases, which apply some algorithms used in the area of neural networks. The authors of Masugi (2002) propose a QoS mapping method of VoIP communications for real network environments. They have been employed a self-organising neural network, which can map high dimensional data into simple geometric relationships on a low dimensional display. By employing a self-organising training scheme, it has been shown that the proposed idea can combine multidimensional QoS-related parameters and project the results onto a two-dimensional space, so that the positioning of QoS level for each condition can be correctly evaluated.

2.2 Molecular computation

Another technique is based on DNA computing (Beigel and Fu, 1998; Chen et al., 2004; Kari, 1997; Qiu and Lu, 2000): thanks to the parallelism available in DNA computing some currently intractable problems could be solved, because contrarily to the traditional approach, the solving process does not need to be started up again when changes in the initial condition occur. DNA is composed of units called nucleotides, distinguished by the chemical group (base) attached to them. Single nucleotides are linked to form DNA strands that can have two chemically distinguishable ends, thus, a DNA strand can be seen as oriented. These characteristics can be exploited in a self-assembly based problem (Amos, 2005).

As in nature, there is the assembling of sample entities to form more complex elements (Atoms form molecule, molecule can form crystal and so on), so the self-assembly is the process by which objects evolve in more complex elements.

DNA has emerged as an important component to use in artificial self-assembly of nanoscale systems, owing to its small size, its incredible versatility, and the precedent set by the abundant use of DNA self-assembly in nature. DNA computing can play a fundamental role in parallel computing (Wąsiewicz et al., 2000): a data flow machine operates differently from a classical von Neumann machine, which computes a sequential program flow, it performs operations when the operands are ready. This data-driven mechanism can be driven by molecular interactions, which means that a specific molecule can recognise another.

2.3 Cellular automata

CA can be considered as a set of locally connected automata nets. Each automaton produces an output as a function of several inputs, modifying its state according to a transition function. In a CA, the state of a cell depends only and exclusively on the states of the neighbouring cells and on its own state in the previous generation. The CAs can be also considered as useful tools for modelling any system in the universe. They can be considered as a good alternative to the differential equations and they have also been used for solving some problems in telecommunication systems. Different fields of research employed the CA concept: as illustrated in Subrata and Zomaya (2003); it can be used for location tracking in mobile computing networks, without introducing too much signalling overhead, which can lead to QoS degradation; for this purpose, an evolutionary CA can be introduced as a model of naturally existing and evolving systems. The studies based on CAs started in the 1940s and the variety of their application fields is very high: for example, in Signorile (2004) the CAs are used for modelling public facilities and to manage crowds in urban environments, capturing the specific characteristics of the individuals in the crowd. Another field of application of CAs regards the simulation of urban traffic (Schreckenberg and Schreckenberg, 1997), by the modelling of traffic flow dynamics with low computational efforts: the collection of individual vehicle data (travel time, numbers of stops, etc.) requires a microscopic approach, which may be too much expensive in terms of computational time; with the help of CAs, the underlying traffic flow dynamics can be well-modelled in an efficient way, associating a single road with a CA; each road is then subdivided into cells, which can be empty or occupied by one vehicle; following this approach large networks in multiple real-time can be simulated. As illustrated, CA is one of the main successful computational paradigms in simulating complex systems, as physical phenomena, represented in terms of connected components (CA nodes) (Calidonna and Furnari, 2004). This kind of system modelling allows the study of two kinds of parallelism: the control parallelism coming from the possibility to execute in parallel more CA belonging to the network; the other one is the data parallelism intrinsic to the CA model.

2.4 Genetic algorithms

GAs are often used to solve combinatorial optimisation problem. In particular, these algorithms are used in those problems that are hard to solve with classic techniques. GAs follow the biological evolutionary principle through some well-defined steps. These steps are Selection, Crossover and Mutation. In order to find the final solution, more generations are explored. Through these steps, it is possible to explore the solution space in different way.

Mutation procedure permits a new point in the solution space to be found. So, it is possible to explore a wide region of space giving the possibility of improving the goodness of the found solutions.

GAs work with a simple data structure that is known as chromosome; each chromosome is composed of several genes. Each chromosome represents a possible solution. Each gene represents a decisional variable that is used in the objective functions. Moreover, in order to discriminate each chromosome, a fitness function is utilised. The fitness measures the goodness of the chromosome. A multi objective optimisation problem can be formulated as follows

$$\begin{aligned} &\min/\max\{\bar{y}\} = f(\bar{x}) = \left[f_1(\bar{x}), f_2(\bar{x}), \ldots, f_n(\bar{x})\right] \\ &\text{s.t.: } \bar{x} = \left(x_1, x_2, \ldots, x_n\right) \in X \\ &\quad \bar{y} = \left(y_1, y_2, \ldots, y_n\right) \in Y \end{aligned} \tag{1}$$

where $\bar{Y}$ is the solutions vector while $\bar{X}$ is the variables vector. Hence $f(\bar{x})$ is the reference objective function that algorithm tries to optimise.

Crossover is the most powerful genetic operator and it permits GA to explore the solution space.

The easiest crossover procedure is the one point crossover, where a single point is chosen to exchange some elements of two parents in order to obtain two new individuals. Furthermore, it is possible to choose different crossover kinds with two or more crossover exchange points, but sometimes multipoint crossover can degrade overall performances.

Mutation operator is a genetic manipulator that permits one or more genes in the chromosome structure to be changed, in order to obtain new individuals with different characteristics. In computational research optimisation, the mutation procedure permits new space solution points to be explored. Without mutation, operator GA could be caged in a local optimum and no more solution could be investigated.

GAs are superior to conventional optimisation algorithms in multiobjective problems because of the following three features (Cui et al., 2003):

1 GAs find a population of candidate solutions composed of more than one candidate solution.

2 GAs use a codified solution in order to execute the biologic operators such as selection, mutation and crossover. In order to find better solution GAs use objective function to evaluate each chromosome that is present into the current generation pool.

3 GAs are often used to solve combinatorial search problem in different research fields. The GAs take advantage of biological evolution procedures in order to create a new generation so as to have better individuals with better fitness values, which means a better solution.

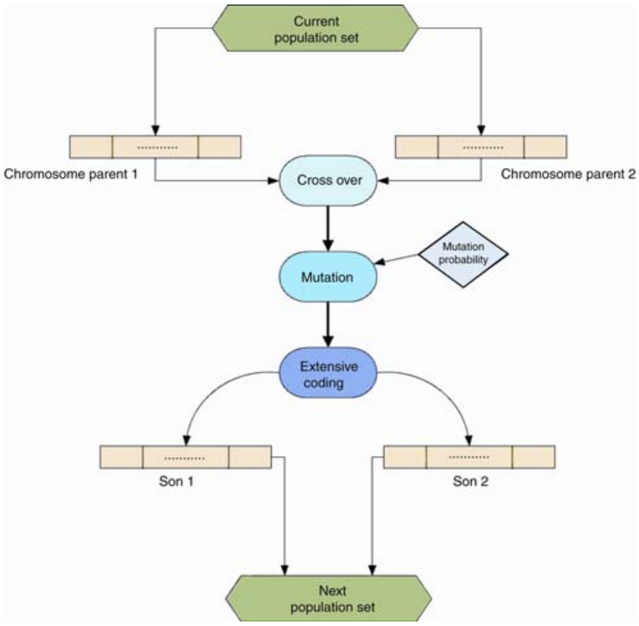
GAs have been widely used in multiobjective optimisation problems to provide a solution based on adaptive heuristic searching within a solution space. Often, objective functions to be optimised, conflict with each other and there may not be a unique local optimum solution. In other words, it may not be possible to improve some objectives without degrading some others. GAs are very powerful tools because they can evaluate different solutions in parallel, and they produce possible different best solutions to multiobjective optimisation problems. GAs, in fact, explore different solutions through the biological operator, such as crossover and mutation. These procedures, if well set, can explore different points of the optimisation problem $P(\Omega(P))$. The main steps followed by a generic GA are presented in Figure 1.

2.5 Epidemic strategies

Traditional computing methods not permit reliability and scalability properties to be met, which are very important characteristics that influence the entire network performances. Thus, in order to obtain a fully distributed control and coordination to perform common strategies to reach a target objective, biologically inspired techniques such swarm-based management policies can be adopted.

The principle of epidemic information dissemination mimics the spread of epidemics and for this reason this technique is known as epidemic dissemination. Another analogy is the spread of a rumour between humans that happen thanks to gossip, this kind of dissemination is also called gossip dissemination.

Figure 1 Biological evolution steps



Epidemic dissemination algorithms are easy to deploy, because they are very simple. Moreover, epidemic algorithms also offer very scalable properties and they exhibit a stable behaviour. This behaviour is also maintained when a network has bad performances in terms of links and process failure. The algorithm permits more than one failure point and in this way the system reliability gracefully degrades as the link failure increase. Epidemic routing has been investigated, observed and analysed in order to carried out mathematical modelling and theories.

Epidemic algorithms are often used in applications such as failure detection, data aggregation (Jelasity and Montresòr, 2004), resource discovery and monitoring or database replication. The results of those applications provided non-trivial issues. Those issues must be investigated before an epidemic algorithm could be used in a real network context.

When an epidemic dissemination algorithm has to be used in a practical setting, specific design constraint, on resource requirement, must be faced. The question to be addressed is:

1 *Membership*: How do processes to get to know each other and how many do they need to know? It is important for every process *p*, receiving a message, to know towards which other processes it must forward the message.

2 This membership relation is the main task when a scalable epidemic algorithms implementation is considered.

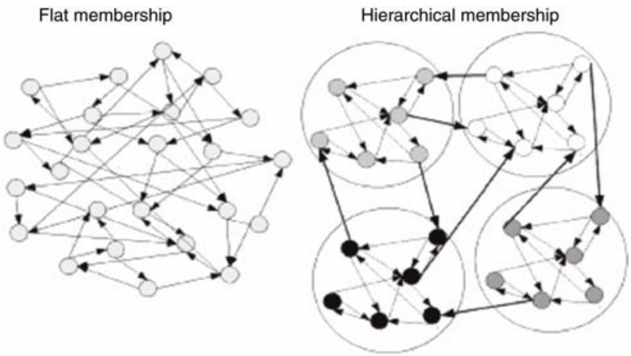
3 *Network awareness*: it is important for propagation of the messages between processes to know the network

state to use the network resource more efficiently. Network organisation knowledge is also important for information dissemination such as shown in Figure 2, where a flat and hierarchical dissemination policy is adopted (Kermarrec et al., 2003).

4 *Buffer management*: What is the information of a process that must be dropped if its storage buffer is full? Often, message buffering cannot occur, owing to buffer overloading, so that, the message could be sent more than once in order to obtain a suitable reliability.

5 *Message filtering*: the discarding of messages uninteresting to a specific process permits the avoidance of buffer space wastage and a more efficient resource management to be obtained.

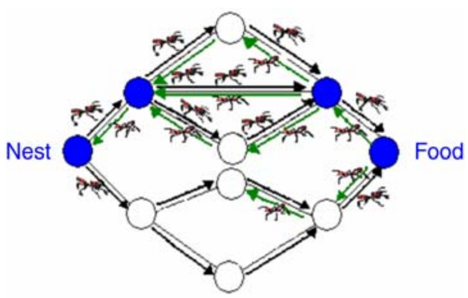
Figure 2 Flat and hierarchical epidemic diffusion



2.6 Swarm intelligence

A new technique based on insect colony intelligence called SI is a form of distributed system. It exploits interactivity between simple entities and with their surrounding environment. Examples of systems based on this natural mechanism include ant colonies, bird flocks, honey bee swarms and so on. In the literature, there are many studies on ant colony behaviour (see Figure 3), used for solving routing problem, energy consumption and so on. SI mechanisms are the basis for the implementation of distributed and adaptive algorithms, and in particular, of routing algorithms.

Figure 3 Ant-colony searching for food



SI algorithms are made up of simple individuals that cooperate through *self-organisation*, that is, without any form of central control over the swarm members. SI is characterised by some principles:

1 *Positive feedback*: it strengthens the best solutions that are in the system.

2 *Negative feedback*: it permits aged or poor solutions to be discarded.

3 *Randomness*: in order to find better solutions.

4 *Multiple interactions*: it permits the best solutions to be found.

Each principle has an important role in the system management. SI advantages are often utilised in order to resolve issues in Mobile Ad Hoc Networks (MANETs), sensor networks and P2P systems.

The SI philosophy is used in order to solve many type of applications. Its main characteristic is decentralised computing, allowing the resolution of many problems in telecommunications filed. Some examples of SI in the context of networking can be found in Shen and Jaikaeo (2005) and Sim and Sun (2003).

Another approach belonging to the SI field is based on bacterial life: a bacterium is an unicellular microscopic organism that reproduces itself by division. Bacteria live in all habitats (e.g. free environments, in many organisms, etc.), so they can adapt themselves to various conditions. Moreover, when millions of bacteria act collectively as a group (as is the case in any bacterial colony), a large variety of different patterns arise as a result of how the individual cells respond to the others in their neighbourhood and to the conditions in their environments (which will be different for different individual bacteria, even if they are relatively close to each other) (Amos, 2005). These patterns are the emergent result of local interactions and environmental conditions and they can be usefully viewed as being programmed by both the specific way the bacteria in question interact, and by the specific way these bacteria respond to environmental signals; so, we can manipulate them in order to formulate, and then to solve, a great number of complex problems. *Bacterial-life* inspired approaches permit good *self-assembly* properties to be achieved.

2.7 Summary

A brief overview of the techniques belonging to the organic computing research field is introduced. Each of these techniques present peculiarities, advantages and drawbacks. It is difficult to select one of these approaches as the best candidate to use in the context of next generation networks and in the autonomic communication field. Some of these approaches, such as epidemic, can be suitable for the *self-reliability* properties associated to info dissemination process. Some other approaches, such as neural networks and SI, are useful for the *self-adapting*, *self-organising* and *self-assembly* properties. On the other hand, GAs can be suitable for the resolution of the multiobjective optimisation and for all the problems where the context is not well known presenting good *self-optimisation* properties.

3 Next generation wireless systems

New generation systems include heterogeneity of broadband wireless and wired systems (see Figure 4), centralised and decentralised communication management, adaptive systems with hard and soft QoS guarantees, P2P and overlay networking and so on.

Figure 4 Heterogeneous next generation network for autonomic communication

Strictly related to the adaptation issue, the previously discussed traditional models rely on a traditional layered perspective of communication systems. This typically prevents the communication medium from adapting to network and application dynamics. On the one hand, the layered architecture makes the higher layers blind with regard to underlying changing conditions (such as a bandwidth reduction caused by a network glitch); on the other, lower layers are unaware of the kinds of service in which they are involved, and so, they cannot customise their activities accordingly (e.g. by the transport layer switching autonomously between TCP and UDP depending on the application it is supporting). Thus, a cross-layered approach is more suitable to new generation wired and wireless systems, in order to get information from different layers and to make more appropriate and timely actions.

Considering a cross-layered approach among distributed systems, it is important in new generation of networks in the view of autonomic communication, to offer important properties such those listed in the following sections.

3.1 Context and situation awareness

As context-awareness and semantic-based reasoning concerns adaptive, networked systems, it requires research about models and languages for representing their behavioural expressions and methods for adaptation that operate on such, possibly semantically rich, representations.

It is widely recognised that managing the structures of a context is a significant challenge. Many systems draw a distinction between context (the low-level information observed or inferred about an environment) and the situation (the high-level scenario in which the system is involved). This frequently involves combining information at different semantic levels. Context has an intuitive connotation in human reasoning. It generally refers to what surrounds the centre of interest, provides additional sources of information 'where, who, what', increasing the understanding. The term 'context' usually has two primary meanings: the parts of a discourse that surround a word or passage and can throw light on its meaning or the interrelated conditions in which something exists or occurs. The first meaning is closely related to linguistics and is the most used definition, whereas, the second meaning is more generic.

From an engineering perspective, in Mostéfaoui et al. (2004) the authors define the context as "any information that can be used to characterize the situation of an entity. An entity is a person, or object that is considered relevant to the interaction between a user and an application, including the user and the application themselves".

Most context-aware systems, make use of external context factors as they provide useful data, such as location information. When dealing with context, three entities can be distinguished (Baldauf et al., 2007): places (rooms, buildings, etc.), people (individuals and groups) and things (physical objects, computer components, etc.). Each of these entities may be described by various attributes which can be classified into four categories: identity (each entity has a unique identifier), location (an entity's position, colocation, proximity, etc.), status (or activity, meaning the intrinsic properties of an entity, e.g., temperature and lighting for a room, processes running currently on a device, etc.) and time (used for timestamps to accurately define situation, ordering events, etc.). An application in the telecommunications field was made in Wegdam (2005), where the authors introduced context-aware knowledge in mobile applications. In this way, mobile applications can react to various environment changes.

In next generation systems, where different technologies can be used by the user to communicate and where the interoperation with different communication paradigms need to be guaranteed, the knowledge of the context or of the situation where a communication operates can become essential for a more efficient and suitable management. In the view of distributed systems, it also becomes more challenging to recognise the context and the situation in a distributed way and to take the appropriate actions on this gained knowledge.

An interesting field in context and situation awareness is represented by protocols that can adapt themselves to environment changing. On the basis of context and situation the users can select the best wireless channel in a multisegment and hierarchical wireless network. In order to determine and/or characterise the environment, neural networks are able to perceive context or human behaviour and in this way adaptive switching technique or wireless access segment selection can be applied to improve the perceived QoS.

3.2 Distributed and decentralised management

In order to overcome the limitations of the client-server paradigm, novel solutions based on distributed architectures are emerging. Among these architectures we recall:

1 *P2P*: systems enable efficient resource aggregation and are inherently scalable since they do not depend on any centralised authority. P2P systems operate generally using a decentralised paradigm.

2 "Overlay Networks: an overlay network is a computer network which is built on top of another network" (Subramanian et al., 2004). Typically, in this kind of network, nodes communicate through virtual or logical links. These links, in the underlying platform are mapped in more real physical links. Furthermore, overlay networks can be realised to allow packet delivery to receivers without specifying an network layer address.

3 In this way, these networks are capable of providing a QoS internet routing without performing any router modification such as in InServ or DiffServ architectures.

4 *Wireless sensor networks*: these kind of networks are, nowadays, employed both in civil and military scenarios, such as monitoring and medical applications, home automation and so on.

Distributed and decentralised networking and management present many advantages such as higher fault resilience, fruition of new kinds of applications, self-organisation, high scalability, mobility support and so on. However, the distributed nature of communication and networking presents also many new challenging problems such as distributed accounting and access control, the deployment of new algorithms for the optimal traffic distribution, of new solutions able to guarantee service continuity and QoS in the case of partial working of the communication system. In addition to these issues, a greater complexity in the development and deployment of the system is present.

A typically decentralised and distributed mechanism known in the literature and becoming very relevant in the telecommunications field is the SI approach. It is capable of exploiting the single intelligence of each individual agent in order to obtain a superior intelligence able to solve complex problems such as routing and resource allocation issues.

An interesting field in the distributed networks is represented by epidemic routing. In particular, when ad hoc networks are considered, which represent a classical type of distributed and decentralised network, the epidemic approach permits the data rate to be maximised, the massage latencies to be minimised and the signal overhead and energy saving consumption to emulate the virus spreading in the body environment.

3.3 Adaptivity

Nowadays, the high growth of different and various wireless applications in telecommunications systems makes them very sensitive to traffic and environmental conditions: different traffic loads are present during the active sessions between mobile users and base stations (or access points) as well as different channel conditions, owing to the instant quality of the wireless link between a generic couple of transmitter and receiver. For these reasons, the different layers of the architecture stack must provide a certain grade of flexibility and adaptivity, in order to make the overall system able to configure itself to different traffic and environmental conditions.

For the physical layer, many works in the literature face the problem of how to dynamically change the modulation scheme or the transmission power, taking into account the requested QoS and the imposed standards constraints; adaptive-modulation schemes with constant transmission power are thus proposed, in order to respect strict delay constraints with the minimisation of the outage probability (Krishnanand and Goeckel, 2004), differently from other works, in which the number of bits transmitted for a given packet will approach its mean (Goeckel, 1999). The outage probability is generally defined as the probability of making a bit error or not being able to meet the delay constraint. Also the varying of transmission power is a key issue, in fact, it can act on the received signal quality and on the energy consumption (Kawadia and Kumar, 2003). Therefore, the power control issue is a classical example of a cross-layer design problem. Classical drawbacks of wireless networks are frequency selective fading and cochannel interference. The first is due to multipath whereas the second, is due to frequency reuse among the various radio cells. The adaptivity in the physical layers inevitably affects the higher levels. In order to implement an adaptive-MAC layer, different requirements must be satisfied: there must be a master control entity that makes some measurements of the variables of interest; the MAC layer must offer a certain grade of scalability of the offered performances (throughput, delay, etc.) as a function of the transmission rate and/or coverage range; in this way, the system is able to adapt itself to the quality of the requested service. In the next generation systems, current store-and-forward routers are going to be replaced with intermediate systems that are able to make on-the-fly computations in order to analyse transient packets and realise dynamic routing algorithms capable of adapting quickly to change the conditions.

A type of network that can belong to this typology is the cellular network. In the cellular systems, it is possible to apply neural techniques in order to perform route prediction. Another application field of neural networks regards the Adaptive Receivers (in particular for CDMA systems): in fact, these devices are able to adapt faster to channel conditions and are more performing respect to others approaches, such as Minimum Mean Square Error (MMSE) and Rake Receiver.

Also GAs can be used in adaptive systems due to their capacity of finding new solutions thanks their specific mechanisms such as mutation, crossover and selection. In particular, GAs can change their configuration for adapting themselves to environment changes.

3.4 QoS support

Mobility management must be always taken into account due to the negative effects (e.g. Doppler shift, heavy multipath fading, etc.) that it introduces when mobile hosts move in the system with their active sessions, while requiring some QoS constraints. Mobility has a high impact on QoS parameters (like packet-delay, delay-jitter and packet-loss rate); when a mobile host changes its coverage cell (i.e. hand-off) with an active flow, the available bandwidth in the new base station (or access point) may be scarce and the congestion level may vary, while the perceived service quality may fall below requested lower bounds; in the worst case, the connection may be dropped. Owing to these problems, deterministic service guarantees, commonly used in wired networks, become inadequate in a wireless scenario and a flexible service model, which allows variable QoS, is needed.

Wireless networking poses special problems, like limited bandwidth and high error rates, due to fading and mobility (Bharghavan et al., 1998) effects. In order to offer an adaptive QoS to mobile hosts an architecture, capable to reserve bandwidth levels and to offer guaranteed services, is introduced. The Integrated Services Packet Networks with mobile hosts and Mobile Resource ReSerVation Protocol (MRSVP) (Talukdar et al., 2001) are used for exchanging state information of the wireless network. The MRSVP is based on active and passive reservations and it is capable of prereserving a certain amount of bandwidth in the current cell (where the call has originated) and in those that mobile host will probably visit, in order to guarantee the desired QoS during hand-off events.

So, in order to handle user mobility and to offer guaranteed services (independent from mobility) the ReSerVation Protocol (Braden and Zhang, 1997) has been extended, with the MRSVP; in this way, the hand-off events can be managed in an adequate manner and the mobile users can make reservation requests over more than one cell, by their *proxy agents*: there are *local proxy agents* (which handle the active reservations) and *remote proxy agents* (which deal with passive reservations). An active reservation is made by a user only on the current access point, while passive reservations are made only on the remote cells that the user will visit during its connection. A MRSVP connection starts with a *proxy-discovery protocol* phase, with which the user can learn the addresses of its remote agents; before making the real reservation request, the mobile host must assure itself that there is enough bandwidth availability on the current cell; the involved access points answer with a positive acknowledgement if possible. When a user goes from a cell to another one, the hand-off event is managed by making a new request (no QoS guarantees) or by a reservation switch (guaranteed services): the reserved resources in the old access point are released in both cases and the passive resources can be assigned by switching to an active reservation.

In order to meet QoS requirements, different techniques can be utilised. Some of these are GAs, SI, epidemic mechanisms. In particular, good results have been obtained with GAs approach in the QoS multicast routing in order to solve multiobjective problems concerning to the search of multicast distribution trees. Also, the SI technique can be used in multiobjective QoS constraints problems like those present in routing protocols that try to find the better path from source to destination with the respect of imposed bounds over QoS metrics such as end-to-end delay, maximum availability bandwidth and others QoS requirements.

3.5 Scalability

Scalability is another important issue in communication system and in computer science engineering, in particular, in parallel algorithm and machine designs (Aljundi et al., 2004; Luke, 1993; Sun and Rover, 1994). The scalability, in the wired-wireless network, depends on specific hardware and software architectures. The network and services heterogeneity has made the scalability challenges more critical. Moreover, the rapid growth and larger diffusion of the main communications infrastructure, internet, has aggravated this problem. Wide networks, for example, internet, have scalable limitations in the case of managing single traffic flows. Currently, scalability is an issue studied in three main computing areas: parallel systems, distributed systems (Imafouo, 2005; Prasad and Murray, 2000), and high speed networking. Scalability is present in some works about internet access services and distributed applications in networks with a lot of nodes (Molinaro et al., 2005). The scalability regards also issues in high speed networks such as routing protocols (Eardley et al., 2002; Ke and Copeland, 2000; Miyamura et al., 2003), QoS for large traffic volumes, internet multicasting and so on.

Scalability for distributed systems is a big issue. Autonomic communication and next generation networks need of self-scalability properties and this means deploying algorithm and protocol able to adapt their way to operate on the basis of the dynamic context and situation. In MANETs, P2P systems and sensor networks the scalability issue is more emphasised due the multiple parameters that need to be considered. It is important to define the right metrics that are associated with the scalability concept in open and distributed systems such as traffic load scalability, topology change and so on (De Rango et al., 2006). In the view of autonomic communication and distributed networking with *self-properties* the scalability becomes a key issue to permit the coexistence of heterogeneous systems and the integration in a unified network completely transparent to the end user. In this context SI (e.g. ant-based systems) can offer self-scalability properties realising through the cooperation of nodes with reduced functionalities also complex task. Ant-systems can be applied to heterogeneous wireless networks such as ad hoc networks (Hussein et al., 2005) or also broadband wireless network such as High Altitude Platforms (De Rango et al., 2007). Moreover, epidemic strategies can be applied in the context of scalable and robust info propagation through data replication and diffusion offering good self-robustness and self-replication properties.

3.6 Security

Security in wireless communications has become an important issue in the last few years especially in a distributed environment like ad hoc networks.

Ad hoc networks, owing to their improvised nature, are frequently established in secure environments and hence they are easily attackable. In the last few years, many secure routing protocols have been proposed. Typically, they make use of cryptographic algorithms to secure the routes and avoid active attacks (Kong et al., 2005). Conventional methods of identification and authentication are not available (owing to the fully decentralised nature of the communication and management), since the availability of a Certificate Authority (CA) (Capkun et al., 2003) or a Key Distribution Centre (KDC) cannot be assumed. Consequently, mobile device identities or their intentions cannot always be predetermined or verified. In MANET adding to the utilise of cryptographic algorithms, Intrusion Detection (IDS) and response mechanisms are needed (Karygiannis et al., 2005). MANETs present a number of unique problems for IDS; differentiating between malicious network activities and spurious but typical issues associated with an ad hoc networking environment, is a challenging task. Malicious nodes may behave maliciously only intermittently, further complicating their detection. A similar approach is given by the trust-based communication: trust-based routing protocols locate trusted rather than secure routes in the networks by observing the sincerity in participation by other nodes (Pirzada et al., 2006). These protocols thus permit rapid deployment along with a dynamically adaptive operation, which conforms with the current network situation.

In this field of applications, the using of molecular computation is interesting. In fact, in the literature, there are many works on Data Encryption Standard, which deal with this technique. In the field of cryptography, the CA can be also used. A use of CA was proposed in the public key cryptography procedure.

3.7 Summary

Next generation communication systems are becoming a hot research issue, because for an efficient management of these networks, multidisciplinary knowledge and cooperation between different research fields is important.

Many properties need to be offered to new generation systems in order to permit ubiquitous computing and any-time/any-where communications. Some important properties need to be offered such as *context-situation awareness*, *distributed management*, *adaptivity*, *hard and soft QoS* support, *distributed scalability* and *security*.

Any of these properties in the view of autonomic communication and the self-properties respect makes for an appealing challenge.

4 Conclusions

In this paper a description of the principal characteristics of a new kind of network inspired on organic computing techniques such as neural network, molecular computing, CA, GAs, epidemic propagation strategies and SI has been attempted. These new systems are becoming very desirable for their capability in resolving many problems in an efficient and distributed manner. In fact, they have many important properties, such as context-situation awareness, distributed scalability, adaptivity and so on. Typically, these systems simulate biological behaviour that, then, are translated into mathematical formulas capable of solving many problems in telecommunications environment. This biological behaviour has the characteristic of learning from successes and failures; owing to multiple adaptive feedback loops, they are able quickly to find optimal solution in the search space.

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