Challenges for Autonomic Network Management

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Abstract. The improvement in the management capabilities and available bandwidth offered by next generation of networks is accelerating the development of a new kind of applications, interfaces and services. The ultimate goal of such networks is to automatically adapt their services and resources in accordance with changing environmental conditions and user needs. Such 'autonomic' capabilities imply the usage of sophisticated technologies in order to integrate every object of our environment that would be enabled with important computational power and storage capabilities. The challenge behind such implementation is to simplify the administrators' task by automating the decision making process, and enabling the users to seamlessly find their way in such pervasive environments. This paper gives an overview of the different architectures that support the design, implementation and deployment of autonomic systems.

1 Introduction

Our future environment is appearing more and more complex and pervasive. It is more complex because the announced technologies require additional management skills; and pervasive because these technologies need to integrate every object of our life while optimizing the control of its powerful local computational and storage capabilities. These objects will be spread in the environment and potentially capable of carrying on some kind-of "smart software codes", which would allow 1) spontaneous communication with neighboring objects using different wireless technologies; 2) continuous monitoring of resources (software or hardware component), and 3) autonomous re-configuration to keep their parameters within a desired range. What we will experience is a smooth and steady shift from our good-old static computer on our desk, connected to Internet through a wire line, to completely mobile devices that are capable of communicating with each other using a wide range of heterogeneous technologies. These smart devices that will surround us (possibly included in our body!) will be able to communicate, coordinate among themselves to achieve their pre-enforced goals: Seamlessly providing us necessary services. We argue that the increasing complexity of managing a large amount of devices, all using sophisticated and heterogeneous technologies, cannot be handled by a traditional "centralized" management approach. Therefore, the solution rests in the distribution of the decision-making process while focusing human attention on the business logic rather than the configuration details. To do so, it is necessary to provide these future objects/devices with autonomic management and control capabilities that allow them to become autonomic nodes — capable of self-governance and spontaneous integration in the managed environment.

The reasoning and decision-making capabilities of each autonomic node should not be based on any precise directive but rather on goal that can be defined by human and interpreted locally by each object depending on its capabilities and environmental context. The 'human' administrator will not have, or at least very little, direct influence on their local and instantaneous behavior, but rather on the boundary of achievements.

What we expect from an autonomic object is the fulfillment of the system and/or human needs from the technological point of view (self-configuring, self-organizing, self-securing, etc.). It should be able to communicate with neighbor elements as in some cases it will not be possible to achieve the goals only locally. These autonomic objects should be able to evaluate the state of their environment in order to accurately adapt their behavior to the situation (indoor, outdoor, climate, human, etc.).

If the technological integration of computational autonomic nodes poses several problems, the seamless integration and cooperation of situated-autonomic communications nodes represents an interesting and novel research challenge. It will not be sufficient to dynamically integrate the nodes from the communication point of view, but it is also necessary to provide them with the means to share their knowledge of what is going on in the surrounding environment. Thus, there are three major aspects to consider when dealing with autonomic systems: 1) how to design an architecture that will support autonomic behavior, 2) How to represent the information that are necessary to an autonomic object to achieve an autonomic behavior. 3) How autonomic object communicate together, organize among themselves in a possibly large context.

In this paper, we present the issues related to the design, implementation and deployment of autonomic networks—We will focus on the autonomic-management approaches. First, we give the motivation behind the emergence of autonomic, self-managed systems and the required features of such architectures. Then, we highlight the different architectures that have been proposed so far. In section 5, we discuss the complexity related to the autonomic information modeling and the autonomic behavior. Section 6 highlights the potential of bio-inspired techniques. Finally, we will give an overview of our future works and conclude.

2 Self-Managing Systems

The essence of the autonomic-computing vision is the human nervous system which is capable to maintain the body in the appropriate equilibrium by interpreting thousands of parameters and accordingly adapt body functions in a very complex manner.

To cope with the increasing complexity of the management process, future autonomic networks and systems should have the ability to govern themselves and dynamically adapt to changes in accordance with high-level business policies and objectives. Therefore, the autonomic network will be able to perform management activities based on situations it observes or senses in the information-pervaded environment. Rather than the system administrator initiating management activities, the system continuously observes a set of parameters while trying to keep them within the desired range using a behavioral schema (*self-governance*). This will allow the system manager to focus on high-value tasks while context-aware agents manage the more basic operations.

The aim of such decentralization process is a reduction of the maintenance and operations cost. System developers will express their needs and the desired state of the system; while model-driven approaches associated to semantically rich behavioral patterns will refine the business/system goals to low level configurations that will dictate the individual behavior of network elements. The distribution of knowledge across components of the system is a critical issue in the design of an autonomic system. The next generation of devices will rest on a rich, extensible knowledge base to optimize their configuration while correlating their behavior with other devices within the same autonomous domain. In this sense, it must be stressed that autonomy is not a characteristic of a single device, component or software, but rather of the system as a whole. Various elements of the system will have to correlate their behavior and addition their different functions to form a system that behaves autonomously. The key elements are: a local knowledge management system, a high availability system and an asynchronous knowledge distribution and decision-making process.

To fulfill the requirements of this new kind of systems, it is important to evaluate them from different perspectives or views: conceptual, functional, architecture, information and behavioral.

The conceptual view serves at identifying and modeling the main concepts that will be referenced by the other views. The functional view aims to identify the autonomic functions/applications that grant a behavior to a system. The architecture view helps in representing the autonomic system as a set of components interacting together to achieve their tasks. The information view captures the structural representation of the system that will help in inferring components characteristics and capabilities. The knowledge representation is very important as it will attach a meaning to the information view and help building a semantic integration schema between system components. Finally, the behavioral view help in drawing an interaction schema optimized for a particular task.

3 Functionalities of an Autonomic System

In order to grant an autonomic behavior to autonomic system, the following functionalities will be foreseen and enabled both at the autonomic node or component as a single point of decision and the whole system.

- **Self-locating**: With this feature the autonomic node establishes, and dynamically updates, a reference system to identify neighbor nodes and locate the resources required by its coordination schema. The reference model will help in the behavior correlation process.
- **Self-configuring**: With the ability to dynamically configure itself on the fly, an information pervaded environment can adapt immediately—and with minimal human intervention—to the deployment of new components or changes in the information-pervaded environment.
- **Self-healing**: Through self-healing, systems state can be evaluated and corrective actions can be initiated without disrupting system operation. The corrective actions may lead the system/subsystem to alter its own state and/or influence changes in other elements of the environment. The information-pervaded environment as a whole becomes more resilient as changes are made to reduce or help to eliminate the impact of failing components.
- **Self-optimizing**: This feature refers to the ability of the information-pervaded environment to efficiently maximize resource allocation and utilization to meet end-users needs with a minimal human intervention. In the near term, self-optimization primarily addresses the complexity of managing system performance. In the long term, self-optimizing components may learn from experience and automatically and proactively tune themselves in the context of an overall objective. Self-optimization verifies optimum Quality of Service for systems users.
- **Self-protecting**: The goal of self-protecting environments is to provide the right information to the right users at the right time through actions that grant access based on the users role and predefined privileges. A self-protecting information-pervaded environment can detect hostile or intrusive behavior as it occurs and take autonomous actions to make itself less vulnerable to unauthorized access and use, viruses, denial-of-service attacks and general failures. The self-protecting capability allows businesses to consistently enforce security and privacy policies, reduce overall security administration costs and ultimately increases employee productivity and customer satisfaction. Self-protection is also about recognizing and dealing with overload conditions that could jeopardize the integrity of the system.
- **Self- and context-aware**: These features refer to perception and cognitive reaction to an event or more generically to a condition, relevant to the same intelligent node or, respectively to the environment. Context-awareness is a foundation for the rest of the operational features: self-configuring, self-healing, self-optimizing, and self-protecting.

4 Autonomic Network Architecture

Autonomic networks, as highly distributed systems, will be constituted of a set of interacting Autonomic Entities (AE). Each individual entity will instrument a set of managed resources, consume services and offer services to human or peer autonomic entities. AEs will manage their own internal behavior and their interactions based on pre-established or on-line agreements. Entities can renegotiate the terms of the agreements in order to define a new form of interaction or collaboration.

The role of an AE is to satisfy the goals specified by the administrator. The architecture of autonomic components require fundamental capabilities that allow every AE to exhibit an emergent behavior i.e. local processing of goals, monitoring of the environment and reaction to contextual events by self reconfiguration or knowledge propagation that will drive interaction with other AEs. This autonomic behavior as well as the interaction with the environment and other autonomic entities may result in a "Collective Intelligence" between network components to achieve the desired goal.

The internal functional architecture of an Autonomic Element is shown in Figure 1 as firstly presented by IBM in 2001 (AC - `http://www.research.ibm.com/autonomic`). This architecture is composed of a number of functional

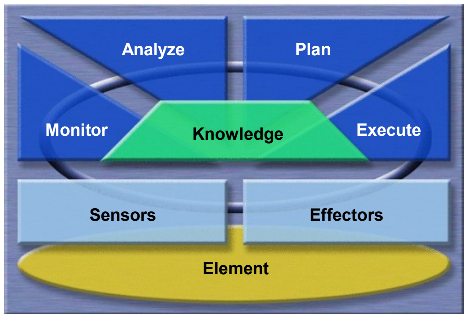

Fig. 1. IBM Autonomic Element Architecture

modules that enable the expected autonomic behavior through a set of autonomic operations. To be really efficient, these autonomic operations are achieved using a self-adjusting control loop [1,2]. Inputs to the control loop consist of various status signals from the system or component being controlled, along with policy-driven management rules [3] that orchestrate the behavior of the system or component. Outputs are commands to the system or component to adjust its operation, along with messages to other autonomic elements.

The Control Module allows an AE to interact with other AEs as well as with its managed entity. It introduces two components called sensors and effectors. Sensors provide mechanisms to collect events from the environment while the effectors allow the configuration of its managed resources.

The Monitoring Module provides the AE different mechanisms to collect, aggregate, filter and manage information collected by its sensors from the environment. Whereas, the Analyze Module performs the diagnosis of the monitoring results and detects any disruptions in the network or system resources. This information is then transformed into events. The Planning Module defines the set of elementary actions to perform accordingly to these events. These actions can be local (re-)configuration or messaging peers AEs.

The Execution Module control the execution of the specified set of actions, as defined in the planning module. Once the goals specified, the interaction workflow between the different modules of the AE allows the router to behave in an autonomic manner without any human intervention. The behavior defines two levels of control over the instrumented managed resources and the AE as a whole: The local control loop of the AE allows reactive behavior, to situation changes in the AE, to be enforced. Another general loop, called global control loop aims to enforce a reflexive behavior of the AE (change the behavior state) regarding more important situation changes in its surrounding environment.

4.1 Cognitive Networks, DARPA

The approach of DARPA is called cognitive networks. The aim of this approach is to put the focus on the cognitive capabilities of this future network architecture. Cognitive architecture aims to reproduce the cognitive processing of humans and implement it on a computational level. Cognitive architectures are characterized by certain properties or goals: the cognitive behaviour should not be implemented partly but it should concern the complete system implementation of various aspects of the cognitive behaviour as well as the complete system (Holistic view of the cognitive system). The architecture aims to reproduce the behavior of the modeled system (i.e. human nervous system) at different level of time (short term, long term reactions) to exhibit a robust behavior to errors and unknown/unexpected events. Finally, the system aims also to learn and adapt its future reactions based on statistics about the previous executions. Even if this approach focus on the cognitive aspects, it is still aligned with the IBM approach, however, they differ in their terminology and definitions.

DARPA proposes an architecture for cognitive nodes that introduces 3 processes related to cognitive behaviours: reactive, deliberative and reflective (meta-management) reasoning process. It retains the same stabilisation loops as presented in the IBM arcihtecture (and the FOCALE architecture presented below.

The “reactive” process provides the cognitive network with capabilities that allows reacting automatically to some events or perception of the environment. However, that sense of “reactive” excludes any possibility to take into account future possibilities, hypotheses about what might have been the case, or formulate hypotheses about what exists in some part of the system that is not currently being perceived. Deliberative process permits to leverage this limitation providing the system with the ability to represent and reason about, and to compare and evaluate, possible situations that do not exist, or exist but are not known

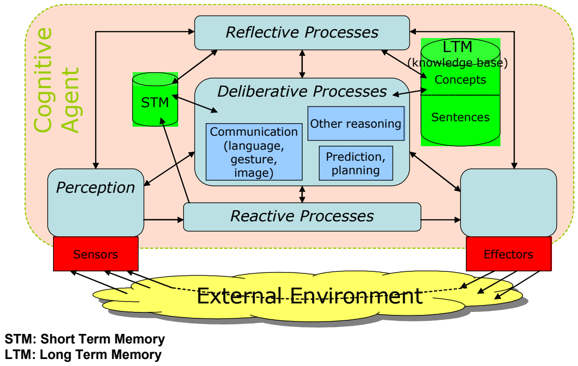

Fig. 2. DARPA Cognitive Architecture

, either because they are future possibilities, or because they are remote or hypothetical possibilities or because they might have occurred in the past but did not [5]. Finally, the reflective process enables the cognitive elements to monitor and control their own progress to adapt their future behavior in response to previous performance. Statistics, or executions history, are an important parameter in the decision-making process.

4.2 Bio-Networking Architecture

The Bio-Networking Architecture developed within the BIONET[4] project at the University of California, Irvine and supported by NSF (National Science Foundation) and DARPA. It relies on biological systems to propose a scalable, adaptive and survivable architecture for autonomic systems. The essence of the architecture is principles and mechanisms that allow biological systems to scale, adapt and survive. The architecture can be deployed using paradigm guides to design autonomic network applications and a middleware that provide software components to build applications. The Bio-Networking Architecture introduces also a middleware on which cyber-entities will exist. Cyber-entities are autonomous mobile agents that are used to implement network applications. The Bio-networking platform provides therefore the execution environments and support services for the cyber-entities. The Bio-Networking approach relies on mobile agent background and therefore reuses some of its concepts. It is not completely clear today whether autonomic network should rely on mobile agents or not but it is obvious that some concepts are similar and the autonomic network community should take benefit from the results in this area and be more innovative in taking into account the specificities of network technologies as well as their heterogeneity, scale, dynamicity and deployment environments. This drives us to the how complex environment are perceived by intelligent entities and how they take it into account. That is the knowledge and information modelling.

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[4] `http://netresearch.ics.uci.edu/bionet/`

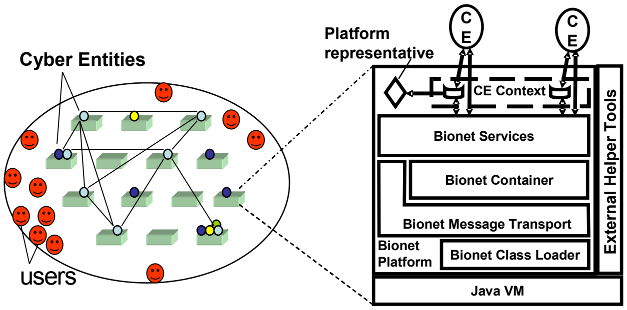

Fig. 3. UC BIO-Networking Architecture

4.3 FOCALE Architecture

The **FOCALE architecture** (Foundation, Observation, Comparison, Action, and Learning Environment) as introduced by Motorola in collaboration with the LRSM Lab of the University of Evry and the TSSG Lab in [4] gives a more detailed view of this autonomic architecture towards the management of networks as shown in Figure 4 below.

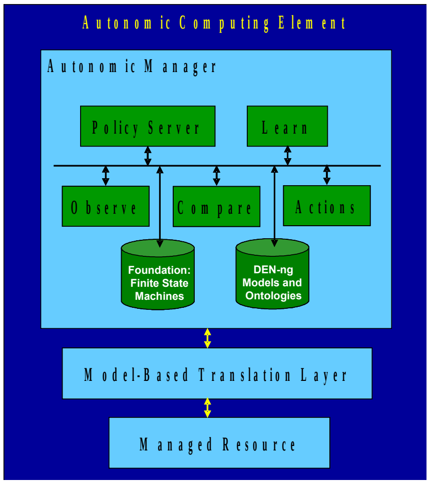

Fig. 4. FOCALE - the Autonomic Computing Element Architecture

This approach assumes that any Managed Resource (which can be as simple as a device interface, or as complex as an entire system or network) can be turned into an Autonomic Component. By embedding the same Autonomic Manager in each Autonomic Computing Element (ACE), it is possible to provide uniform management functionality throughout the autonomic system (AAMCs and AEMCs). This is then expanded, first to a uniform Autonomic Management Domain and then to an Autonomic Management Environment (Figure 5), which consists of a set of Autonomic Management Domains.

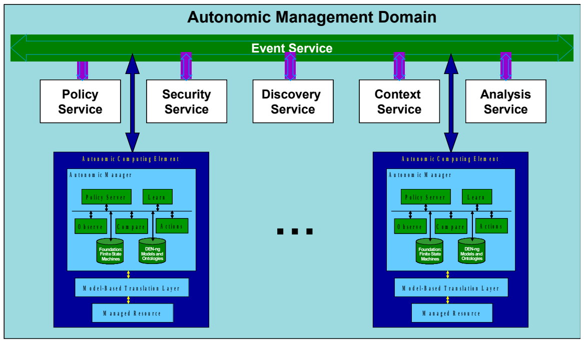

Fig. 5. FOCALE Autonomic domain

Other initiatives are on going on autonomic communication either in US and Europe. DARPA and NSF have launched a number of research project grouped in two initiatives for DARPA called Architectures for Cognitive Information Processing [5] (ACIP) and Biologically-Inspired Cognitive Architectures [6] (BICA). The European commission has also launched in its 4th call of the FP6 (Research Framework Programme) a long-term research initiative in the area of Situated and Autonomic Communication: BIONETS [7], ANA [8], HAGGLE [9], CASCADAS [10] as well as a coordination project called ACCA [11] which coordinates and integrates new proactive initiative in the area of self-organization (self-management, self-healing, self-awareness, etc.).

5 Information Modelling

Autonomic components must keep their parameters within a desired range but also interoperate with each others in order to maintain the network in the desired state. Such emergent behavior will facilitate network configuration and management by enabling features like:

1. Self-configuring interface and schema alignment across data vocabularies, directory taxonomy, service descriptions, and other components.

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[5] `http://www.darpa.mil/ipto/programs/acip/index.htm`
[6] `http://www.darpa.mil/ipto/Programs/bica/index.htm`
[7] `http://www.create-net.it/bionets/aree/overview/index.php`
[8] `http://www.ana-project.org/`
[9] `http://www.cambridge.intel-research.net/haggle/eu/`
[10] `http://netmob.unitn.it/cascadas/index.html`
[11] `http://www.autonomic-communication.org/projects/acca/index.html`

2. Self-optimizing transactions, routing, queries, and transformations.
3. Self-healing error flows that can recover from otherwise dead-end use cases.

The challenge behind such implementation is the representation of knowledge at the resource manager level: unification and simplification of business processes and information technology across the management domains. Instead of relying on a unique information model, we argue that the solution is to cover different standards thus allowing interoperability between semantically equivalent, but heterogeneously instantiated, domains knowledge.

Autonomic Manager must rely on a precise and scalable knowledge base. Considering the number of standardization organizations, associated specifications and proprietary implementations of the standards: relying on a unique information model is not realistic, thus, we need to provide to the autonomic manager (runtime process) a way of integrating management models/processes used by different stakeholder dynamically.

Existing operator's management domains do not (and probably will never) adopt the same representation for their managed entities (user profiles, applications, and network service) including their properties, relationships and the operations that can be performed on them. Therefore, we need a robust foundation of information, data and semantics in order to integrate different source of information into a uniform model that can be used by a run-time process to perform federated queries from a single (abstract) query statement, without having to standardize on a particular format or vocabulary or re-key databases to conform to a uniform model.

Diverse management domains rely on heterogeneous system specification defined by different organizations: TMF, DMTF, OMG, IETF, 3GPP, ITU, etc. or instantiate multiple data models from the same information model. The challenge is the integration; derivation and transformation of data from multiple sources in a distributed, transparent and scalable manner, thus, we need to establish a set of requirement to perform such integration:

1. Define a common terminology and concepts relevant to a particular user or application.
2. Define input, output, constraints, relationships, terms and sequencing information relevant to a particular business process or set of processes.
3. Define the structure and content restrictions relevant to a particular interface (API, Database, scripting language or content type)

With a robust foundation of information, data and semantics as a baseline, new capabilities for interoperability can emerge:

1. Data Interoperability - semantic interoperability of data enables data to maintain original meaning across multiple business contexts, data structures and across schema types by using data meaning as the basis for transformations
2. Process Interoperability - semantic interoperability of process enables specific business processes to be expressed in terms of another by inferring

meaning from the process models and contextual meta-data and applying it in a different process model elsewhere or outside the organization

3. Services/Interface Interoperability - semantic interoperability of services enables a service to lookup, bind and meaningfully communicate with a new service without writing custom code in advance
4. Application Interoperability - semantic interoperability of applications enable the granular interactions of methods, transactions and API calls between heterogeneous software applications to be platform independent
5. Taxonomy Interoperability - semantic interoperability of taxonomy enables any category to be expressed in terms of other categories by leveraging the intended meaning behind the category definitions
6. Policy Interoperability - semantic interoperability of policies and rules enables businesses to protect valuable resources regardless of what technologies their security mechanisms have been implemented in or how complex the rights management issues have become.

6 Bio-inspired Autonomic Network Management

As described in the previous section, the aim of autonomic communications is to minimise and alleviate human intervention, and allow communication devices to cooperatively communicate and perform decision process in order to exhibit self-governance properties. The notion of autonomics embodies a number of functionalities that allows large-scale network systems to exhibit self-governance behaviour. As described in section 3, self-governance behaviour includes abilities for network devices to cooperatively self-manage, self-protect, self-organise, etc. A number of these properties can be found in nature, and distinct examples are biological systems. In principle biological mechanism are robust and have tremendous capabilities to adapt to fluctuating environment. Biological systems follow the same concepts, where sensors in biological systems sense the changes within the environment and enable the organism to adapt to the environment through a set of operations and rules. Biological fundamental traits in autonomics would create more opportunities for more efficient management and will provide characteristics such as individual element self-healing, self-repair and can also be extended to overall system self-management, self-configurations, and self-optimisation. Applying biological analogies towards various fields and disciplines of science has led to more efficient techniques to solve problems. Notable successful examples of drawing inspirations from biological analogies include Artificial Neural Networks, Molecular computing, or Genetic Algorithms. Swarm intelligence has contributed towards self-organiation and self-management of systems, by mimicking for example a school of fishes that organise and cooperatively swim in a coordinated swarm [6].

By mapping these biological principles towards local rules within Autonomic Element (AE) allows them to cooperate cohesively to support high level objectives. This section will describe some key example biological principles that can be applied to AE, to support the requirements described in section 3 and 4.

Our intention is to draw out these key mechanisms and map them to biological systems through some key biological design paradigms.

6.1 Challenges of employing bio-inspired analogies

Although Biological models do pose similar characteristics that are required by Autonomic networks, mapping Biological analogies to AE's do present some research challenges. Initially, finding a direct analogy match to support a requirement in the network domain is extremely difficult. The pragmatic approach that we follow is to look at a set of candidates for analogies first, then to choose the best candidates, where we then refine and combine different analogies [7,8,9]. Since obtaining a direct biological analogy mapping is not a practical solution, we first identify key biological mechanism that will closely resemble the requirements of network management, where we then select a particular model and refine to simplify to suit the requirements of a networking problem. The combination of different analogies poses the most challenging problems, which includes (i) finding the right integration that can support other analogies, and (ii) combining analogies that will not result in conflicts or degradation of performance. Although using this methodology will lead to system that is quite different from original biological system, our intention is to obtain self-governance (self-management, self-adaptability, self-configuration, etc) properties from the resulting combination. The combination of the aforementioned challenges, which is illustrated in Figure 6, makes the work with bio-inspired techniques very interesting and promising though it is a long way to have practical solutions.

The introduction described the high level complexity found in current networks, which requires a de-centralised approach for local decision making to support global properties of Autonomic Network characteristics. The introduction also described the requirement for AE, to have the ability to sense changes within the environment and interpret these changes and take corrective action. These characteristics as described above are found in biological systems, where Figure 6 illustrates a mapping process from bio-inspired mechanisms to AE, in order to achieve high level global objectives that encompass autonomic capabilities. The principles from biological systems can be mapped to AE's, and allow AE to exhibit these autonomic capabilities. As shown in Figure 6, biological systems have a mechanism to detect the environmental changes, and through local rules within each organism, are able to support characteristics such as maintaining equilibrium and support adaptation as well as survivability in face of any drastic changes. These are some of the characteristics which are required in AE, where devices are required to have properties such as coordination with neighbouring devices and detect environmental changes and take local corrective action.

6.2 Biological Principles

In this section we outline some important biological principles which we map towards AE. The biological principles described in this subsection have been

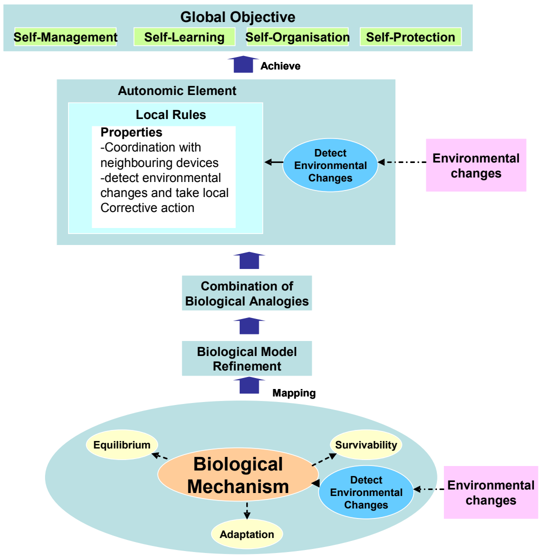

Fig. 6. Employing Biological mechanisms to achieve autonomic capabilities

applied to various applications of engineering. We have drawn out some of these mechanisms that can contribute towards designing an architecture that supports autonomic behaviour.

Homeostasis. It is a characteristics found in living organisms that enables the ability to maintain system equilibrium. There are various different forms of homeostasis within living organisms that function cohesively to support sustainability. The concept of homeostasis is analogous to a control feedback look, which consist of both positive as well as negative feedback. Based on specific events, the feedbacks are triggered to invoke corrective actions to stabilize the system in the event of any changes. Events are usually triggered from hormone signals that can get invoked from various systems (e.g. nervous system). Hormone signals are transmitted to specific cells of tissues, where the receptors bind to specific hormone messages and invoke the corresponding corrective action. Some examples of homeostasis include thermoregulation, osmoregulation, and balancing of blood glucose level. The thermoregulation is ability for the human body to maintain stable internal body heat. Factors that may invoke instability in the body heat may include rise in internal body heat due to intense body workout, which sets an event to correct the body temperature through production of sweat. Osmoregulation is a process for balancing of water level within the body. The blood glucose homeostasis, illustrated in Figure 7, is the ability for the body to maintain the glucose level irrespective of intensity of the body activity, where glucose is converted to energy through respiration including Aerobic and Anaerobic respiration. In the event of glucose depletion due to excessive body workout, the glucose is obtained from other forms such as glycogen or fat. When a cell receives a hormone signal, the balancing process is performed by intracellular communication between the cells, where intracellular communication is performed by diffusing chemical signals to neighboring cells.

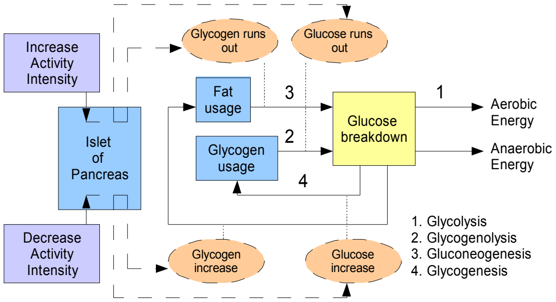

Fig. 7. Blood Glucose Homeostasis

Reaction Diffusion. This concept was devised by Alan Turing as a computational model to describe self-organisation. Turing's finding supported the idea that nonlinear interaction between species from diffusing chemicals can lead to formation of spatial patterns. The chemicals that are diffused between the cells are known as morphogens, where the two types of morphogens include an activator and inhibitor. Based on the activator and inhibitor morphogen, Turing illustrated that self-organisation can results from the random fluctuation, chemical reaction, as well as diffusion.

Chemotaxis. The process of taxis in micro-organisms allows movement based on stimulus attraction to supports the ability for self-adaptation. This guided movement can be in response to positive or negative stimuli. One type of taxis used for micro-organism mobility is chemotaxis, which is the movement in response to chemical build up in the environment. Chemotaxis process can be both positive (e.g. movement to food source) or negative (moving away from poison). Figure 8 illustrates a positive chemotaxis.

Neural System. It present one of the first and very successful bio-inspired examples. The neural system within a living organism supports the ability for organisms to process and act upon stimuli (both external and internal). Although various living organisms's neural systems ranges in ability and functionality, the process is crucial towards the development such as growth and learning. Based on experience, organisms have the ability to interpret sensory input that generates effector output and processing this information in the brain. The units used to interpret and produce these signals are known as neurons, where the neurons usually function as a network. Based on the patterns of these networked neurons within the brain tissue, the experience can help the brain learn from these external stimuli.

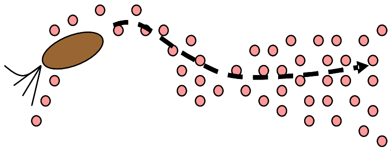

Fig. 8. Chemotaxis

Immune System. The immune system is a natural defence mechanism of the human body that responds to foreign invaders. These foreign invaders are commonly known as pathogens. Immune systems in living organisms can come in two forms, which can be inherited at birth (innate) or acquired during the lifetime of the organism (adapted). In the event of pathogen attack, the organism's innate immune system initially overcomes the infection. However, at times, the strength of the pathogen usually overcomes the power of innate immune systems which requires the organism to turn towards adaptive immune system. The adaptive immune system consists of two types of cells, which includes B and T-lymphocytes cells. The B and T cells have receptors on their surface that allows the cells to bind to pathogen, through a pathogenic material known as an antigen. The binding will occur once the affinity between the two goes beyond a specific threshold. The stimulation of B-cells is usually from the successful binding of antigen to the T-cell. Once the B-cell is stimulated beyond a specific threshold, the cells transform to a blast cell which produce large amounts of clones.

The production of these clones is in proportion to the affinity binding between the antigen and the T-cells. The production of these clones also produces large amount of antibodies, which undergo somatic hypermutation to increase the diversity of the immune response. These antibodies will in turn remove the antigen from the system. At the same time the immune system also contains immune memory of the cells, so in the event of exposure to the same antigen, a quicker response can be invoked. [10]

6.3 Design principles of Bio-inspired mappings to Network Management

Figure 9 illustrates mapping from a number of biological principles that can contribute to local rules within AE to support self-governance. Although the principles illustrated are independent, they are highly dependent and support overall self-governance.

Mapping of Homeostasis. The Homeostatic model supports overall system equilibrium. As shown in Figure 9, various external factors interface to the corrective action of the system to maintain overall system stability. These factors maybe caused by external stimuli, such as node/link failures or addition of new equipment to expand communications systems, or changes from internal stimuli such as changes in loads of nodes due to increase in network traffic. The rules for maintaining overall systems equilibrium are translated to local rules within each AE. Such rules may include interpreting the neighbouring node's load in networks to determine free resources within a specific region of the network (e.g. a traffic path drops out, leading to free resources in interconnected links of part of a network; can be applied to both core networks as well as ad hoc networks). The free resources within the network, will lead to instability within the network, which can lead to corrective action to stabilise the system through allocation of resources for new incoming traffic. The Blood glucose analogy gives a good perspective towards mechanisms to manage network resources as well as the varying traffic types, where glycogen and fat represents the resources within the links of the network while the optimal usage of these resources for different traffic types (e.g. data and multimedia) is compared to the respiration model [8].

Mapping of Reaction Diffusion. The Reaction Diffusion support peer-to-peer interaction between devices through local message exchanges. The Diffusion process, permits the diffusion of morphogens that indicate the state of the device (e.g. current load on the node), where the receipt of these morphogens from neighbouring devices can invoke state changes within the devices, where the state changes represents the reaction process. Therefore, a mapping process is formed to map external events relating to state of neighbouring devices that can lead to changes with the state of a device. An example is when resources from neighbouring devices changes, where the collection of devices can support traffic path with higher Quality of Service [9]. The reaction diffusion mechanism is invoked in a peer-to-peer fashion between devices and their neighbours, where the changes can slowly propagate throughout the network. The morphongen classification can map the different chemical types, which correspond to the different traffic types, as well as the concentration of the chemical which correspond to the amount of free resources between devices.

Mapping of Chemotaxis. As described in the previous section, chemotaxis supports the mobility of micro-organisms through a formation of chemical gradient. This mechanism can be used through cooperation of devices to form chemical gradient to support various migration applications. Examples of these migration applications include routing of packets between nodes from source to destination in core networks, or support for service discovery amongst mobile ad hoc devices. Our application of determining routing paths uses chemotaxis mechanism in conjunction with the reaction diffusion techniques described above, where the chemical gradient guides the packets to the destination and is based on calculation of node loads as well as information such as distance of the nodes to the final destination (hop count) [9]. Similar to the reaction diffusion principle, different chemical gradients can represent different traffic types and different concentration can support the amount of bandwidth available along the path. For service composition application, chemotaxis can be used to guide services composition with other services in the environment.

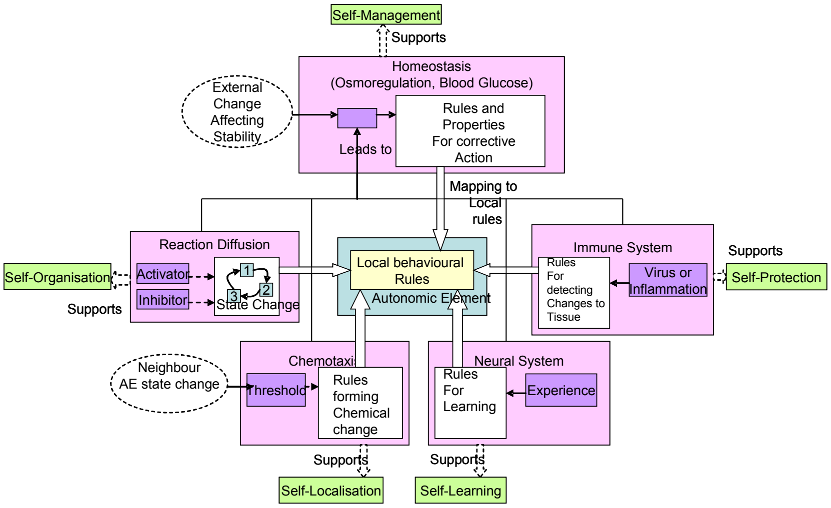

Fig. 9. Mapping key biological principles to Autonomic Element

Mapping of Neural System. The neural system of Autonomic Elements can help guide device behaviour and decision process based on past experience. The past experience for core network can be the different network traffic types (e.g. VoIP, VoD), as well as profiles of traffic (e.g. demand traffic, fluctuating traffic). Examples of AE's that are required to make decision based on past experiences may include the ability for routers to perform decision on dropping certain traffic profiles in the event of overloaded links. Based on past experiences, network of neurons within the routers can determine the effects of dropping packets and compare to the effects of system level with regards, for example, to the revenue output. Learning mechanism can be performed through learning algorithms such as the back propagation.

Mapping of Immune System. As described in section 3, a crucial characteristic for autonomic networks is self-protection, which allows service providers to enforce required security policies amongst AE. Through efficient self-protection mechanisms, threats to customers can be minimised without the need for security experts to continually monitor any imminent attacks on the networks. As described in the previous section on Immune systems, the B-cells are used by the adaptive immune systems to overcome pathogens. Examples of this application to network security can be to detect malicious attacks from unauthorized users that could affect network performance or affect specific customers. Since B-cells contain immune memory, and B-cells have the ability to share and interact with other B-cells. The neural system can be used in combination with the immune system to learn from past attacks to avoid any attacks in the future.

Since real immune systems have numerous identical B-cells to deal with different types of infection, it is difficult to have a similar system in Artificial Immune Systems. Therefore, the concept of Artificial Recognition Ball, has been developed, to represent a particular antigen space, where a network of artificial balls for a particular antigen space can detect suspicious cells that do not fall within this space [10]. This is performed by calculating the distance of new cells from the artificial balls within the antigen space to determine the degree of how genuine the cell is. Using this mechanism, antigen space can be developed to determine genuine packet stream from demand profiles traffic and suspicious packets from unexpected or fluctuating traffic. Through the neural system, the antigen space can be continually refined as the new suspicious traffic is encountered.

7 Furture directions

Our future work will extend the architecture described in [11] and called G-Based for Goal Based Autonomic Management Architecture. We will focus on the cooperative behavior of autonomic elements called Autonomic Cells (AC) and the representation and translation of high level goals into low level objectives. This architecture reuses the concepts introduced by IBM, DARPA and Motorola but will also provide a support for the seamless integration of heterogeneous network management models. Instead of relying on a unique standard, we will provide an ontology-based integration mechanism that should allow an AC to dynamically integrate new management definitions and descriptions.

The specification, processing and distribution of knowledge is central to our architecture. We define a goal as a semantic association between systems resources. When associated to a Goal, an autonomic element becomes a part of an entire autonomous system (i.e. regrouping of elements with a single objective). All the elements associated with a single Goal are viewed as a single autonomic entity though an element can be associated to multiple Goals. Consequently, the behavior of an autonomic element can be driven by its knowledge and the Goals it has to fulfil. The ability of the autonomic element to deal with multiple Goal definitions (multiple business requirements) is handled by the Goal language. Its settings will allow the detection of unpredicted conflicts between objectives of various providers.

In the same time, we will continue our investigations on the bio-inspired models and particularly the scalability of their behavioral patterns. Indeed, when the network topology increases, it is challenging to evaluate the achievement of the desired goals without a scalable control mechanism. We believe that bio-inspired

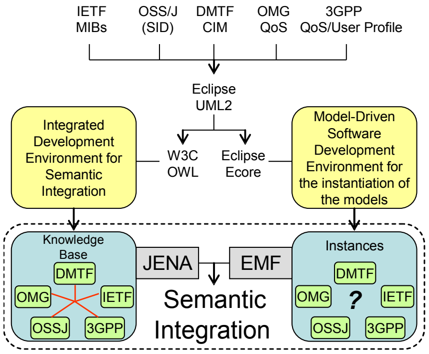

Fig. 10. Semantic Integration

techniques will help in the design of intelligent behavioral mechanisms for Autonomic Components — this will reduce the complexity of managing Autonomic Systems.

8 Conclusion

Next generation networks will certainly face changing situations in the environment, from the users, the operators, the business requirements as well as the technologies. Users will be more and more mobile requesting access from different parts of the network. The heterogeneity of communication and application softwares, protocols, etc. will increase and render the network more complex to manage. This predicted complexity make nowadays network architecture obsolete and new approaches should be initiated. Autonomic networking is one of these initiatives that aim to design networks that are capable to self-manage, while optimizing their configurations and interactions to the changing needs of the users and the environment.

In this paper, we have presented the essence of the autonomic networks vision: the human nervous system as well as biological systems in general. We have introduced several initiatives that implement to same functionalities but with different approaches. We believe that the knowledge is the most important part of the autonomic-system. How knowledge is represented? How it is update locally or remotely? How information are translated into knowledge? How reasoning and adaptation is achieved on this knowledge? How to reason on limited part of the global knowledge? All these questions are still open and we believe that the right responses will be the key of the problem.

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