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Introduction

The opening, context-setting, chapter introduces the background behind the concept of autonomic computing, and accounts for its convergence with modern networked systems. A conceptual analysis is then carried out in order to draft a fully-fledged framework depicting the scientific advancement in this respect. In essence, the general vision and the state of the art in the field of autonomic computing are approached from the viewpoint of the related mechanisms inherent in the functioning of the human autonomic nervous system. Given its importance, this consists in the analysis of the key dimensions of self-configuration, self-optimisation, self-healing, and self-protection, altogether known to constitute the notion of self-management, and is extended to cover the pertinent architectural assumptions and variations complemented with insight into the overlapping nature of autonomic computing and agent systems. Then, the ultimate question of convergence between autonomic computing and autonomic networking is addressed, and, thus, the ground for the discussion of the role of self-awareness is settled, with the eventual goal of introducing the target Autonomic Cooperative Networking Architectural Model. In order to make this possible, first the investigation of the most recent incarnation of the Generic Autonomic Network Architecture is characterised with special attention paid to the explanation of the role of decision elements and hierarchical autonomic control loops, along with their respective levels of abstraction, presented in an incremental order, starting from the lowest protocol level, through the function level and node level, up to the top network level.

Once the related ground has been settled, the scope of the Autonomic Cooperative Networking Architectural Model is examined in more detail through the introduction of the Vertical Technological Pillars and the Horizontal Architectural Extensions. In fact, the layers of the Open Systems Interconnection Reference Model are made perpendicular to the levels of the Generic Autonomic Network Architecture in order to identify the key architectural challenges to be addressed by the ultimate Autonomic Cooperative Networking Architectural Model. For this reason, an incremental conceptual outline is presented involving the key architectural components in the form of the Autonomic Cooperative Node, Autonomic Cooperative Behaviour, and Autonomic Cooperative Networking Protocol, as well as the major decision elements of relevance. In particular, first, the protocol level cooperative transmission decision element is presented with its responsibility for virtual multiple input multiple output channel based and distributed space-time block coding enabled cooperative relaying. Next, the function level cooperative re-routing decision element is deployed, with its role of being a trigger for transmission resiliency driven cooperative re-routing. Moving forward, the

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node level cooperation management decision element is introduced in order to facilitate the integration between cooperative relaying and routing mechanisms. Last, but not least, the network level cooperation orchestration decision element is presented as being accountable for comprehensive oversight of the overall system. All in all, a high-level blueprint of the Autonomic Cooperative Networking Architectural Model is drafted to be further advanced in the chapters to follow.

The third chapter follows on with specific architectural considerations. In particular, the presentation is started with the foundations of the protocol level spatio-temporal processing, where the initial emphasis is laid on developments related to the multiple-input multiple-output channel to provide a good understanding of its workings. Then, the pertinent diversity-rooted origins of spatio-temporal processing are discussed, so that it becomes possible to clearly justify its role and the necessity for its later deployment. Moreover, the question of radio channel virtualisation is visited, where the singular-value decomposition theorem is explained in order to introduce the notion of an equivalent virtual multiple-input multiple-output radio channel to be deployable among Autonomic Cooperative Nodes. The related radio channel capacity is incorporated into the bigger picture of the opening analysis to account for its linear scaling with the number of so-called generic transmitters or generic receivers. Finally, a specific model for radio channel coefficient calculation, to be referenced throughout this book, is described, and the difference between coding gain and diversity gain is addressed for the sake of clarity. Given such a context, the focus moves towards space-time coding techniques, to account for their superiority over the above-mentioned diversity techniques and to pave the way for their later use in networked configurations, where the concept of distributed space-time block coding is expected to prevail.

In particular, the most baseline approach to space-time coding is presented with special attention paid to space-time block coding, where the question of its being perceived more as a modulation rather than a coding technique is visited. Then, the derivation process of the decoding metrics for a selected set of space-time block coding matrices is outlined with the aim, among others, of clarifying certain inconsistencies the author came across in the referenced source materials. Based on this, an extension towards space-time trellis coding is also presented, where additional coding gain becomes clearly visible. Eventually, after all the aforementioned technological aspects have been analysed, their relation to the protocol level control logic is discussed in the light of the prospective architectural integration aspects. To this end, the notion of an Autonomic Cooperative Node is introduced as one of the major building blocks of the proposed concept. Not only is the relation between autonomics and cooperation discussed further, but the internal structure of the Autonomic Cooperative Node is scrutinised. Next, the cooperative transmission decision element is brought into the global picture as belonging to the protocol level, while being mostly responsible for the interaction with the routines of the physical layer. Given such a context, not only is the role and notion of the concept of a protocol addressed, but a pertinent adaptive logic is presented, where the relevant code matrices are switched on the basis of the radio channel parameters. Finally, all the architectural integration aspects of relevance are outlined and the way is prepared for further extensions.

In the fourth chapter, the topics of both conventional and cooperative relaying are addressed from the classificatory perspective; the two approaches are characterised, and the forwarding strategy and protocol nature of the latter are further investigated. Following this, the focus is redirected towards the question of supportive and collaborative protocols, introduced as subcategories of a generic cooperative protocol. Such an approach means that the former shall be considered as a preparatory phase for the latter, making the interaction between the two highly correlated. Going further, the concept of virtual antenna arrays is outlined on the basis of its most versatile multi-tier incarnation, where, assuming a generalised cooperative transmission scheme, its special operation mode of distributed space-time block coding is discussed as being clearly intended to play a crucial role for all the further developments to be discussed in this book. Given such a context, attention is directed towards a fixed deployment concept, where both the conventional and cooperative relaying techniques could become equally applicable, yet the plot is advanced on the assumption that the subject of subsequent analyses will be the mobile deployment concept. In particular, the grid-based Manhattan scenario is initially outlined to underline that as much as the pattern formed by the buildings could become critically important for the suppression of interference among the fixed relay nodes, it would make it literally impossible to exercise any cooperative relaying based on virtual antenna arrays.

In essence, the evaluation effort is carried out to highlight that, despite limitations related to cooperative relaying, certain link layer and network layer performance optimisations would still be possible. To this end a specific adaptation strategy is proposed with regard to the framing structure and the buffer memory, so that, using the process interaction simulation method, it becomes possible to observe improved packet throughput at the network layer. Similarly, a cooperation-enabled relay-enhanced cell indoor scenario is analysed, where the major emphasis is put on the link layer aspects, keeping in mind its applicability to any later mobile deployment concept considerations. Eventually, the focus is shifted towards the function level overlay logic, where, first of all, the roots of Autonomic Cooperative Behaviour are outlined to account for its role and complexity, including its enablers – the equivalent distributed space-time block encoder in particular. Then, the rationale behind the cooperative re-routing decision element is presented, including its transition from the node level to the function level and the logic behind cooperative re-routing involving the role of the fault management decision element and the place of the resilience and survivability decision element. Last, but not least, the architectural integration aspects are discussed to account for the general dependencies between the routines of all three layers of interest, as well as to provide a more detailed insight into the architectural relations driven by the pairing of the link layer and the function level, complemented by the introduction of a specifically extended version of the Autonomic Cooperative Node.

In the fifth chapter, first of all the workings of the experimentation-related version of the Optimised Link State Routing protocol are discussed, with special emphasis on its functional and structural characteristics related to the field of applicability and the assumed messaging structure. Apart from the proactivity-driven relevance to mobile ad hoc network scenarios, special attention is paid to the multi-point relay station selection heuristics with the incorporation of certain small alignments. Additionally, the information storage repositories are analysed in order to provide the required context for further developments, and specifically to introduce new elements in the form of both the VAA selector set and its related VAA selector tuples, intended to become the enablers of the target concept of enhancing cooperative transmission with routing information. What follows directly are the developments originating from the routing information enhanced algorithm for cooperative transmission, conceived by the author as a method for applying the additional information collected by the Optimised Link State Routing protocol inherent in the network layer, and its modified version in particular, for the sake of both enabling and orchestrating cooperative transmission at the link layer. To this end, the justification for the introduction of the routing information enhanced algorithm for cooperative transmission is provided with particular emphasis on the relevant algorithmic description, where, additionally, certain elements and nomenclature of the Optimised Link State Routing protocol are assumed, predominantly because of a fairly direct usage of the outcome of the multi-point relay station selection heuristics.

Given such a context, the elevated concept of the extended routing information enhanced algorithm for cooperative transmission is outlined along with the evolved messaging structure in order to lay the groundwork for the target Autonomic Cooperative Networking Protocol. In this respect, both the very vital topics of address auto-configuration and duplicate address detection are considered, before the focus shifts more towards the umbrella formed by the function level overlay logic. In this way the workings of the Autonomic Cooperative Networking Protocol are outlined, covering the role of the extended routing information enhanced algorithm for cooperative transmission in its conception, as well as justifying the place of the evolved messaging structure in the process of Autonomic Cooperative Node preselection, along with the layout and the reasoning for the related design of the routing table. The extended algorithmic description defining the logic of the cooperation management decision element is then examined in reference to what was previously outlined for the original routing information enhanced algorithm for cooperative transmission. Based on this it becomes possible not only to evaluate the advantages thereof by means of simulation analysis, but also address the overhead aspects of the evolved messaging structure. Finally, the entire analysis is elevated even further to conclude with aspects of the architectural integration, covering the roots of the Autonomic Cooperative Networking Protocol, the conceptual transitions, and the related dependencies among its architectural entities.

In the final chapter the standardisation-orientated design is introduced, assuming a research and investment driven perspective, in order to explain the origins of the Autonomic Cooperative Networking Architectural Model by touching on issues related to the standardisation of the Open Systems Interconnection Reference Model, as well as emphasising the role of prestandardisation related to the Generic Autonomic Network Architecture. What naturally follows is a description of the staged instantiation of the Generic Autonomic Network Architecture Reference Model, depicting the progression of various levels of abstraction in an incremental manner. This introductory part is concluded with certain cross-specification-related considerations intended to incorporate select concepts from software-defined networking, machine-to-machine communications, and intelligent transport systems into the bigger context of the Autonomic Cooperative Networking Architectural Model. Then another, highly practical, deployment scenario in the form of an emergency communications network is considered, which becomes especially interesting because of its being driven by a combination of specifically tailored requirements, where safety appears to take priority over the latest technological advancements. In particular, it is emphasised that the system operation becomes bound to exercise the hierarchy between chief first responders and their respective first responders, as implied by human established relations. In this respect, the relevant network topologies are discussed along with the related configurations of chief first responders.

The way is thus prepared for further incorporation of autonomic routines, since, after the cooperative mode of operation has been introduced and the proactive and reactive resiliency process has been outlined, the integration of the emergency communications network into the ultimate Autonomic Cooperative Networking Architectural Model may be discussed. Following the complementary justification for the cooperative enhancement in question, supported with performance evaluation analysis, the related network level overlay logic is introduced to the overall picture to encompass any still outstanding or not comprehensively addressed workings of the Autonomic Cooperative Networking Architectural Model. In this way the mutual relation between the Autonomic Cooperative Networking Protocol and the Autonomic Cooperative Behaviour is presented from the perspective of the priority between the two, on the grounds of their being inherent in the respective dimensions of the Open Systems Interconnection Reference Model and the Generic Autonomic Network Architecture. Based on this, the notion of the cooperation orchestration decision element is introduced in a way emphasising more tangibly when the Autonomic Cooperative Behaviour may be prioritised over the Autonomic Cooperative Networking Protocol. In particular, the relay-enhanced cell scenario is revisited under certain additional assumptions allowing for a more accurate evaluation of the second hop. Finally, the architectural integration aspects are raised to address the mutual operation of all the discussed decision elements to introduce additional synergy to the fairly exhaustive depiction of the Autonomic Cooperative Networking Architectural Model.