Autonomic Cooperative Networking

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INTRODUCTION

Since the number of devices interconnected worldwide is growing drastically, the question of the orchestration of the durability-orientated operation of networked systems becomes critically substantial. In fact, durability understood in context of network resilience translates into the provision of the key features of reliability, availability, safety, confidentiality, integrity, and maintainability. To this end, it is advocated for the integration of networking with the rationale behind autonomic computing in terms of self-configuration, self-optimisation, self-healing, and self-protection. This article goes one step further as it presents the concept of Autonomic Cooperative Networking (ACN), which not only capitalises on the above-mentioned concept but also incorporates the novel notion of Autonomic Cooperative Behaviour (ACB). ACB stems from and is being triggered by the idea of distributed cooperative transmission, aiming to enable collaboration among devices, enhanced with the integration of the relevant network layer routines. This way the devices are expected to share their computational capabilities and memory to perform joint data processing for the benefit of meeting the global performance indicators through increased resilience.

Obviously, as such a system grows, it appears necessary, from the local perspective, to instantiate cross-layer integration of certain aspects with the use of a network protocol in order to limit any unnecessary control overhead resulting from the exchange of data among the cooperating devices. Yet, as today's distributed systems are becoming more and more complex, the transition from the local to a more global perspective additionally requires the incorporation of an autonomic overlay so the routing-enabled distributed cooperative system may self-manage. Going further, the paradigm of autonomic system design assumes that such a networked system should follow the operating principles of the human autonomic nervous system and, thus, be able to self-configure and, then, self-manage without any external intervention. Autonomic design has its own area of applicability and it should not be confused with autonomous or automated systems. While autonomous may, on the one hand, pertain to being stand-alone, and, on the other hand, to being cognitive, automated is mostly done by means of scripting. The difference in meaning does not exclude, however, certain dose of synergy so that autonomics, understood as self-management, could be supported through the inclusion of autonomous and automated routines.

The idea of Autonomic Cooperative Networking is expected to become one of the key emerging technologies behind the concept of Autonomic Future Internet. At this time it is undergoing the pre-standardisation path within the Industry Specification Group (ISG) on Autonomic network engineering for the self-managing Future Internet (AFI), functioning under the auspices of the European Telecommunications Standards Institute (ETSI). In particular, it is applicable to ad-hoc and mesh networks and the author of this article is serving as a Rapporteur of ETSI AFI on the Autonomicity-Enabled Ad-hoc and Mesh Network Architecture which is preparing a Group Specification (GS) in this area (Wódczak, Meriem, Chaparadza, Quinn, Lee, Ciavaglia, Tsagkaris, Szott, Zafeiropoulos, Radier, Kielthy, Liakopoulos, Kousaridas & Duault, 2011). To account for the above, the article is organised as follows. First, the concept of cooperative transmission is described through the introduction of the idea of Virtual Antenna Arrays (VAA) in order to pave the ground for further analysis. Following, it is complemented with the incorporation of the relevant routines of the network layer with special emphasis on the Optimised Link State Routing Protocol (OLSR) and its Multi-Point Relay (MPR) selection heuristics. Finally, the routing enabled cooperation is translated into Autonomic Cooperative Behaviour (ACB) being integrated directly into the Generic Autonomic Network Architecture (GANA).

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BACKGROUND

As the number of globally interconnected devices is becoming substantially large, the resulting networked systems are getting prone to configuration issues and resilience becomes one of their key characteristics. Following the rationale behind self-management in autonomic computing, the main trend in networking nowadays is to put emphasis on the ability of a networked system to self-configure, self-optimise, self-heal, and self-protect without any explicit need for external human intervention. This is crucial for complexity reasons, as a complete automation appears to be the only reasonable and justified way forward. In particular, devices may improve the related system robustness by sharing their computational resources through the application cooperative transmission schemes being elevated to the level of ACB. For this reason the autonomic system design behind the Generic Autonomic Network Architecture is applied to synergise both the concept of Virtual Antenna Arrays and Multi-Point Relay selection heuristics of the Optimised Link State Routing protocol, so that very large set-ups composed of a significant number of devices may be considered to imitate the operation of the human autonomic nervous system. This is achieved with the aid of properly extended GANA overlay autonomic network architecture allowing for the overall system to be controlled by specific Decision Making Entities interacting among themselves and operating within control loops.

AUTONOMIC COOPERATIVE NETWORKING

Cooperative Transmission

Cooperative relaying, also known as cooperative transmission, is undoubtedly one of the key advancements in the realm of mobile communications intended to facilitate the mitigation of the impairments induced and imposed by the characteristics of radio propagation (Pabst, Walke, Schultz, Herhold, Yanikomeroglu, Mukherjee, Viswanathan, Lott, Zirwas, Dohler, Aghvami, Falconer & Fettweis, 2004). In general, it stems from the technique of conventional relaying which operates as depicted in Figure 1 and is known under the name of Layer 3 Decode-and-Forward (L3DF) scheme (Herhold, Zimmermann & Fettweis, 2004). This approach usually consists of two consecutive phases. Initially, the Source Node (SN) sends its data to a Relay Node (RN), which fully decodes the received signal, then re-encodes it, and transmits to the Destination Node (DN). Unfortunately, even though such an approach makes it feasible either to reduce the transmitted power or extend the range of radio transmission, it does not offer any relevant diversity gain. In fact, it is referred to as L3DF because, taking into account the Open Systems Interconnection (OSI) Reference Model, the operation of relaying is performed at the network layer (Herhold, Zimmermann & Fettweis, 2004).

Cooperative relaying, instead, is based on collaboration among intermediary nodes, where some of them act as RNs to assist the process of transmission between the SN and DN (Doppler, Redana, Wódczak, Rost & Wichman, 2009). An example is depicted in Figure 2, where the process of transmission is also carried out in two phases, somewhat similarly to the aforementioned L3DF, yet cooperatively. In this case, during the first stage, already both the DN and RN are assumed to receive the transmitted signal. Only after that may the RN additionally resend its copy towards the destination in order to, potentially, improve the transmission performance through the provision of the so desirable diversity. In fact, there are a number of different variations of cooperative relaying known and this idea may also be referred to as cooperation diversity, cooperative diversity, virtual antenna arrays or coded cooperation (Herhold, Zimmermann & Fettweis, 2004). In this article, however, the term of cooperative transmission is generally preferred, as it appears to be the most generic one (Wódczak, 2012).

Figure 1. Conventional relaying