SFB 637
Autonomous Logistics

Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

Historical Development of the Idea of Self-Organization in Information and Communication Technology

Markus Becker, Koojana Kuladinithi, Andreas Timm-Giel, Carmelita Görg

Communication Networks, Otto-Hahn-Allee - NW1, University Bremen, 28359 Bremen, Germany

Information and Communication Technology includes many different concepts, implementations and usages of Self-Organization (Serugendo et al. 2004; Czap et al. 2005; Brueckner et al. 2005). These are among others: ad hoc routing, autonomic communication, Self-Star and peer-to-peer networks.

The constituting features of autonomous control, as already mentioned in Chapter XXX, have been used and enhanced since the beginnings of Information and Communication Technology.

Non-centralised or **distributed** design and operation is naturally present in ICT systems: The components of the ICT networks are distributed, e.g. the base stations of cellular networks, are distributed over the coverage area.

Heterarchy is present in non-hierarchical networks, e.g. peer-to-peer networks, as explained later in this chapter.

User-Network-Interaction and Network-Network-Interaction, as specified for example by the Border Gateway Protocol (BGP), make up the constituting property of **interaction**.

Non-determinism exists, e.g., in the Internet for packets taking different routes to reach the same destination.

Each Internet router acts **autonomously**, which is another constituting property of autonomous control.

Finally, the **decision process** is also found in ICT systems: for example in policy-based decision processes.

Those constituting features can be found in the following examples of ad hoc routing, peer-to-peer networks, autonomic computing and autonomic communication.

Ad hoc Networks

Definition of ad hoc networks

An ad hoc network is a self-configuring network of hosts that have equal or similar functionalities and equal or similar responsibilities (Blazevic et al. 2001; Garbinato and Rupp 2003). Especially important for the functioning of the network is the routing functionality that has to be present in all nodes. Usually this functionality is implemented only in a subset of network nodes, called routers, which provide this service also to those nodes which do not have this functionality. The functionality of ad hoc networks is especially challenging in wireless and mobile environments. The term ad hoc network usually implies a wireless ad hoc network. In this kind of network the nodes communicate by means of radio frequency transmission. A mobile ad hoc network, abbreviated MANET, is a wireless ad hoc network, in which the nodes are free to move. The links between the nodes are created by the routing functionality. The geometric arrangement of the nodes together with the links is called the topology of the network. Ad hoc networks have a dynamic topology due to the movement of the nodes. The routing protocol adapts the topology to the physically possible communication links.

Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

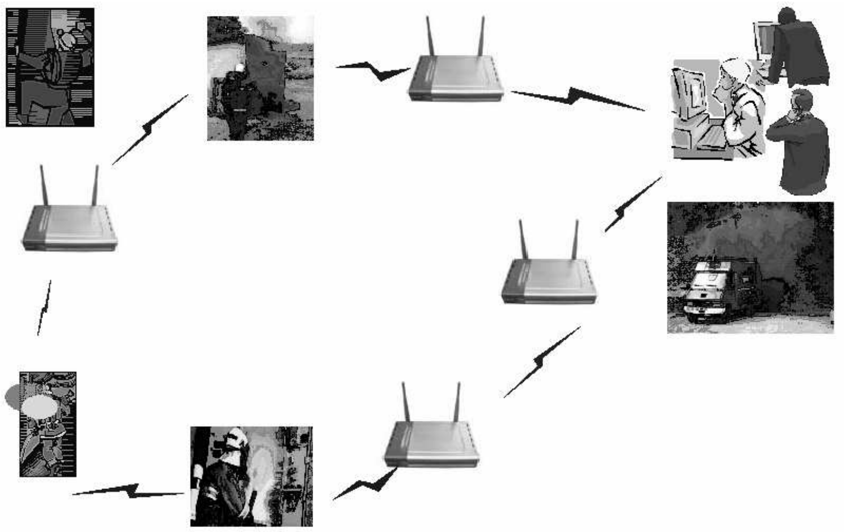

Figure 1 Ad hoc network usage scenario

An ad hoc network can include nodes from non-ad hoc networks, e.g. the Internet. Such nodes may provide access to the Internet for the other nodes of the ad hoc network. This extends the area covered by the Internet-node – usually called Access Point – without the need for installation of further Access Points or infrastructure cabling.

Ad hoc networks have several advantages over usual infrastructure networks:

- Ease of deployment: Ad hoc networks do not need the elaborate setup of Access Points, e.g. cabling, addressing, setup. Although in this case the usage is limited to the ad hoc network with no access to the Internet.
- Speed of deployment: As setup is easier, the deployment is also faster and cheaper (no network and power cabling).
- Decreased dependency on infrastructure: Single points of failure are eliminated, e.g., Access Points.

Characteristic properties of ad hoc networks are:

- Decentralized: Each component has the same functionality, rights and responsibilities. There is no central instance.

- Self-organized: Routes are found without manual or central interaction.
- Self-deployed: Except for physically placing the nodes and switching them on, no setting up needs to be done.
- Dynamic network topology: Depending on the propagation conditions the topology of the network can be changing and is handled by the ad-hoc network.
- Local knowledge: There is no central instance in the network that has knowledge of the complete network. All components of the network only have local knowledge.
- Interaction and cooperation of the elements/nodes of the network: The components work together to find routes to other components.
- Adding/removing nodes is dynamic: Once a new node is added, it announces itself and answers requests for routes in the same way that all other nodes are functioning as part of the network. When a node is removed, the routes using this node break. This break is detected and a new route is set up by the remaining nodes.

The dynamism in wireless systems is very high compared to wired networks. The attachment and detachment of nodes to the network can be more frequent, as there is no physical attachment necessary via cables.

Routing in ad hoc networks

The main functionality of ad hoc networks is the routing protocol. There are two main families of routing protocols: reactive and proactive routing protocols. An extensive list of routing protocols can be found in (Various Authors 1 2006). Hybrid versions of the two different routing approaches are a natural extension.

Reactive Routing Protocols

Protocols that create routes, only if requested by the user of the network are called reactive routing protocols. Examples are: *Ad-hoc on Demand Distance Vector* (AODV), *Dynamic Source Routing* (DSR) and *Dynamic MANET On-demand* (DYMO). Reactive Protocols are

SFB 637
Autonomous Logistics
Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

more appropriate, when the topology is highly dynamic. New routes, which appear frequently, need not be propagated through the whole network, as they are not needed by the hosts most of the time.

Proactive Routing Protocols

Protocols that maintain a list of routes to other nodes are called proactive routing protocols. *Destination-Sequenced Distance Vector* (DSDV), *Optimized Link State Routing* (OLSR) and *Source Tree Adaptive Routing* (STAR) are examples for such protocols. Proactive protocols are advantageous over reactive ones, when the topology is only slowly changing. These protocols do not require generation of routes, when a node wants to communicate, thus the initial delay is shorter.

Autonomic Address Assignment

A very important aspect of ad-hoc networks, which is ideally suited to highlighting the issues associated with self-organisation, is the area of address auto-configuration in ad-hoc networks. Address auto-configuration selects the Internet Protocol Address of devices autonomously without the need for a central instance (e.g. a Dynamic Host Configuration Protocol server). In a static network autonomous configuration of IP addresses can be done by a mechanism called link-local addressing. In dynamic mobile ad hoc networks, however, the situation is more complex. First, not all stations are within a distance of one hop of each other (i.e. not having a direct link). Additionally, there is a possibility of two MANETs joining to form a new MANET with members with the same assigned addresses. These circumstances need to be handled in a self-organized fashion by MANET protocols. A comparison of different techniques can be found e.g. in (O'Grady et al. 2004).

History of ad hoc networks

Mobile ad hoc networks are derived from so called packet radio networks of the 1970s. These projects were sponsored by the American Defense Advanced Research Projects Agency (DARPA). In

Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

1983 the Survivable Adaptive Network (SURAN) project supported a larger scale network. With the common use of IEEE 802.11 components, an increased academic interest could be observed starting in the mid 1990s.

An *Internet Engineering Task Force* (IETF) working group was established, called MANET (Mobile Ad Hoc Networks). The term MANET was introduced by the IETF MANET charter. A variety of ad hoc network routing protocols have been discussed and promoted by this working group (Various Authors 2 2006, Wikipedia Authors 1 2006).

The development of AODV (Perkins et al. 2003) is based on *Destination-Sequenced Distance Vector* (DSDV), which is a protocol for static networks. AODV is an improvement over DSR (Johnson et al. 2004) by reducing the overhead needed for the routing. OLSR (Clausen et al. 2003) as a proactive protocol is derived from *Link State Routing* (LSR). AODV, DSR and OLSR are currently experimental *Request for Comments* (RFCs) of the *Internet Engineering Task Force* (IETF). The integration into standard track RFCs is done by merging DSR and AODV to a protocol called DYMO (Chakeres et al. 2006) and by enriching OLSR with ideas from other protocols to a protocol called OLSRv2 (Clausen et al. 2006). There are further efforts in unifying protocols from the two domains – reactive and proactive – into a common protocol with extensions specific to each domain.

Mesh and Sensor networks

Specific kinds of ad hoc networks are mesh networks and sensor networks. Mesh networks are specific MANETs that consist of mostly static mesh routers and try to supply a backhaul service to mesh clients. In the past there have been several community initiatives to build such systems in urban areas, cf. (Aguayo et al. 2003; Various Authors 6 2006; Various Authors 7 2006). Similar solutions as in MANETs are used in mesh networks, additionally self-organization is exploited with regard to Dynamic Channel Allocation (Akyildiz et al. 2005; Subramaniam 2006).

Wireless Sensor Networks (WSN) are a recent research field (Karl and Willig 2005; Akyildiz et al. 2002). WSNs combine MANETs with low-power design and the ability to sense and/or actuate. Self-organisation in the area of WSNs is focused on enabling lower energy consumption and thus a prolonged life time of the battery-powered devices. An example of this is the adaptation of the duty cycle (the ratio of time awake and time asleep) to the context of the WSN as done for example in (Neugebauer et al. 2005).

Active Networks and Mobile Agents

The autonomous control in data communication is present in the 7 layers of the ISO/OSI reference models (1: physical, 2: link, 3: network, 4: transport, 5: session, 6: presentation, 7: application) in various aspects and names.

It is called Active Networks in the lower layers. The transmitted data packets are accompanied by code components, which are executed at the transit nodes (routers). This leads to a certain degree to an independence of the version of the router. More important is the possibility of autonomous control, i.e. each data packet chooses individually on its handling. (Ledezda et al. 1998)

In the higher layers autonomous control is called Mobile Agents, which are moving autonomously and cooperatively in the network and aim for individual goals, representing the user. Mobile agents extend the concept of agent technology as described in (Jennings and Wooldridge 1995) by the ability to move the agent to the location of the data. The applicability and performance of mobile agents has been studied by (Straßer and Schwehm 1997; Helin et al. 1999; Farjami et al. 1999; Hartmann et al. 1999; Yang et al. 2002). The general aspects of Agent technology are described in Chapter XXX.

Peer To Peer Networks

Peer to Peer Networks (P2P) are another incarnation of the self-organization idea in the information and communication technology field. Contrary to the traditional Client-Server-Architecture, all computers have the same or at least similar functionality like in ad hoc networks (Various Authors 3 2006). The nodes are called peers or “servents” to represent a combination of server and client. The predominant purpose of P2P networks is the retrieval and distribution of content, such as multimedia files. These networks have to handle the addition and removal of nodes to and from the network smoothly.

There are two families of P2P networks. Hybrid P2P or centralized P2P networks have peers that act as servers and client-peers are connected in a star-like fashion to a single super-peer. These super-peers handle special functionalities, such as the indexing of the content or the distribution of search requests. Pure P2P or decentralised P2P does not have super-peers, and all the peers have identical functionalities and responsibilities.

The oldest Peer to Peer Networks are Usenet and FidoNet. The most well-known, recent ones are Napster, Kazaa, Gnutella, eDonkey, JXTA and Bittorrent, (Androutsellis-Theotokis and Spinellis 2004).

Peer to Peer Networks currently also find applications in the context of Voice over Internet Protocol (VoIP), where the voice data of the telephone calls is transported by a P2P network (Baset and Schulzrinne 2004).

Autonomic Computing

Technological systems are growing rapidly in size and complexity. In order to enable further growth of information technology systems, the Autonomic Computing Initiative was started in 2001 by IBM, (IBM Press 2003; Kephart 2003; Ganek 2003). The aim is to allow control of the growing complexity.

Increasing complexity necessitates more specialists, if there is no change to the way ICT systems are currently being handled. Those specialists might not be available or affordable. Usually these specialists have to maintain systems that have been created by a different set of specialists. Maintenance specialists cannot know everything about the system and the side effects of actions.

Furthermore, dependency on information and communication technology (ICT) systems and the monetary losses due to their failures are increasing. Many companies and organisations from many different economic sectors such as banks, IT companies, electrical power plants, police, and military organisations are highly dependent on the availability of their ICT systems. Autonomic Computing has therefore become a topic of interest for academia as well as major companies such as IBM, Sun, DaimlerChrysler and Fujitsu-Siemens (Gu et al. 2005).

Autonomic Computing is a concept of self-managed computing systems with minimum human conscious awareness or involvement, derived from the human autonomic nervous system – a sophisticated autonomic entity.

Autonomic Elements are supposed to be the composing elements of autonomic computing. An autonomic element consists of the managed element and an autonomic manager. The autonomic manager consists of components that monitor, analyze, plan and execute based on knowledge that is available or has been gathered. The autonomic manager therefore acts as a control loop. The control loop describes how the resource and control interact with each other. The resource is measured and based on the measurements a decision is taken and the decision controls the resource.

The building blocks of Autonomic Computing are the self-* principles, that is self-configuring, self-optimising, self-healing, and self-protecting (Babaoglu et al. 2004; Wikipedia Authors 2 2006).

There are different levels of Autonomic Operations stated by (Ganek and Corbi 2003), starting from basic, managed, predictive, adaptive to autonomic systems. Gradually the manual handling involved decreases and the autonomic handling increases over these levels. The autonomy will be visible in processes, tools, skills as well as in benchmarks.

Autonomic Computing principles are already applied in middleware, database systems, and software engineering.

Autonomic Communication

Closely related to Autonomic Computing is Autonomic Communication (Smirnov 2004, Various Authors 4 2006; Various Authors 5 2006), also called AutoComm. Autonomic Communication tries to solve the same set of problems for the Communication area, that Autonomic Computing is tackling largely for the Information Tech-

SFB 637 Autonomous Logistics

Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

nology. The Autonomic Communication Forum initiative is founded on the belief that a radical paradigm shift towards a self-organising, self-managing and context-aware autonomous networks, considered in a technological, social and economic context, is the only adequate response to the increasingly high complexity and demands now being placed on the Internet (Wikipedia Authors 2 2006).

In Communication Technology the situation is similar and closely connected to the situation in Information Technology. The high demand for specialists in these fields cannot be satisfied (Bitkom 2003). The product innovation cycle is accelerating in such a way that the integration of older systems cannot be satisfied in time. Additionally the usage of and number of components of communication system is increasing. This requires distributed and self-organising structures, relying on simple and dependable elements that are capable of collaborating to produce a sophisticated behaviour of the system.

The technologies enabling this are so called self-* technologies, namely self-configuration, self-healing, self-optimisation and self-protection. Self-configuration describes the ability to automatically (re)configure components of the network, self-healing the detection and treatment of errors. The automatic surveillance and control of the usage of resources for an optimal usage of those resources is called self-optimisation. Self-protection is characterized by the ability to identify and prohibit attacks on components.

One key aim of Autonomic Communication is to enable zero-effort deployment. This describes the deployment of a network of communication units without having to do any configuration steps other than putting the units into place. The units will configure themselves in co-operation with the other units.

Key research areas of self-management are currently to answer the questions related to:

- Controllability: How is the ownership reflected in the process, when autonomous elements are negotiating with each other? What happens if an autonomous element cannot be controlled because of its ownership?
- Reliability: Does reliability emerge when autonomous elements are collaborating or does the unreliability increase?

- Security: How are the autonomous elements secured against unwanted control by other elements?

The history of autonomous control in Information and Communication Technology goes back to the 1950s. It started with research on what is now known as the Internet. Today's applications of ICT already heavily depend on autonomous control and this will increase in future as networks are growing.

Conclusions & Future Directions

This chapter introduced the development and the application of self-organization in Information and Communication Technology. It summarizes how the idea of self-organization has been applied in ad hoc networks (including mesh and sensor networks), peer to peer networks, autonomic computing and autonomic communication.

As shown in this chapter self-organisation has been a continuous theme during the past evolution of ICT. In future more sophisticated self-organisation ideas need to be included in ICT to cope with the increasing complexity. As one example context adaptivity can be named. This topic is of relevance in all communication areas from sensor networks to satellite networks. The context is spread over all functional layers of a communication system. A self-organized context adaptation taking into account information from all layers is one of many research topics. Additionally, research is needed with respect to stability issues of self-organisation in ICT (Dolev 2000). In the CRC 637 self-organization concepts are being used in the demonstrator "Intelligent Transportation System" based on Radio Frequency Identification, Wireless Sensor Networks and Agent Technology, as introduced in Chapter XX. The demonstrator is continuously being enhanced based on the self-organisation principle.

References

Aguayo D, Bicket J, Biswas S, De Couto D (2003) MIT Roofnet: Construction of a Production Quality Ad-Hoc Network.

Akyildiz I, Su W, Sankarasubramaniam Y, Cayirci E (2002) A survey on sensor networks, IEEE Commun. Mag. 40 (8) 102--114.

Akyildiz I, Wang X, Wang W (2005) Wireless mesh networks: a survey, Computer Networks 47 pp. 445–487.

Androutsellis-Theotokis St, Diomidis Spinellis D (2004) A survey of peer-to-peer content distribution technologies. *ACM Computing Surveys*, 36(4):335–371 (doi:10.1145/1041680.1041681)

Babaoglu O, Jelasity M, Montresor A, Fetzer Ch, Leonardi St, van Moorsel A, van Steen M(2004) Self-star Properties in Complex Information Systems: Conceptual and Practical Foundations (Lecture Notes in Computer Science).

Baset S A, Schulzrinne H (2004) An Analysis of the Skype Peer-to-Peer Internet Telephony Protocol.

Bitkom (2003) Innovationen für Wachstum und Beschäftigung - Das 10-Punkte-Programm der ITK-Wirtschaft 2003/2004, Bundesverband Informationswirtschaft Telekommuinikation und neue Medien e.V. http://www.bitkom.org/files/documents/BITKOM_10_Punkte_Programm_2003_23.09.03.pdf

Blazevic L, Buttyan L, Capkun S, Giordono S, Hubaux J-P, Boudec JY (2001) Self-Organisation in Mobile Ad Hoc Networks: The Approach to Terminodes, IEEE Communications Magazine, pp 166 -173.

Brueckner S, Serugendo G, Hales D, Zambonelli F (2005) (Eds.): Engineering Self-Organising Systems, Third International Workshop, ESOA 2005, Utrecht, The Netherlands, July 25, 2005, Revised Selected Papers. Lecture Notes in Computer Science 3910 Springer 2006, ISBN 3-540-33342-8

Chakeres I, Perkins C (2006) IETF Draft: Dynamic MANET On-demand (DYMO) Routing.

Clausen T, Jacquet P (2003) IETF RFC 3626: Optimized Link State Routing Protocol (OLSR).

Clausen T, Dearlove C, Jacquet P (2006) IETF Draft: The Optimized Link-State Routing Protocol version 2.

Becker, M.; Kuladinithi, K.; Timm-Giel, A.; Görg, C.: Historical Development of the Idea of Self-Organization in Information and Communication Technology. In: Hülsmann, M.; Windt, K. (eds.): Understanding Autonomous Cooperation in Logistics - The Impact on Management, Information and Communication and Material Flow. Springer, 2007

Czap H, Unland R, Branki C (2005) Self-Organization and Autonomic Informatics.

Dolev Sh (2000) Self-Stabilization, MIT Press.

Dressler F (2006) Self-Organization in Autonomous Sensor/Actuator Networks. 19th IEEE/ACM/GI/ITG International Conference on Architecture of Computing Systems - System Aspects in Organic Computing (ARCS'06), Frankfurt, Germany, Tutorial.

Farjami P, Görg C, Bell F (1999) A Mobile Agent-based Approach for the UMTS/VHE Concept. In: Proc. Smartnet'99 - The Fifth IFIP Conference on Intelligence in Networks, 1999, pp. 149-162.

Farjami P, Görg C, Bell F (1999) Advanced Service Provisioning based on Mobile Agents. In: Proc. MATA'99 - First International Workshop on Mobile Agents for Telecommunication Applications, 1999, pp. 259-272.

Ganek AG and Corbi TA (2003) The dawning of the autonomic computing era. IBM Systems Journal, vol. 42, no. 1, pp. 5-18. ISSN 0018-8670. Publ. IBM Corp., Riverton, NJ, USA.

Garbinato B, Rupp Ph (2003) From Ad Hoc Networks to Ad Hoc Applications. ERCIM News No. 54, July 2003. SPECIAL THEME: Applications and Service Platforms for the Mobile User.

O'Grady JP, McDonald A, Pesch D (2004) "Network Merger and its Influence on Address Assignment Strategies for Mobile Ad Hoc Networks", in Proc. of IEEE Vehicular Technology Conference Fall 2004, Los Angeles, CA, USA.

Gu X, Fu X, Tschofenig H, Wolf L (2005) Towards Self-Optimizing Protocol Stack for Autonomic Communications: Initial Experience. I. Stavrakakis and M. Smirnov (Eds.), Proceedings of the 2nd IFIP International Workshop on Autonomic Communication (WAC'05), Springer Lecture Notes in Computer Science Vol. 3854 (LNCS), pp. 186-201. Athens, Greece.

Hartmann J, Evensen R, Görg C, Farjami P, Long H (1999) Agent-based Banking Transaction & Information Retrieval – What About Performance Issues? In: Proc. European Wireless'99, 1999, pp. 205-210.

Helin H, Laamanen H, Raatikainen K (1999) Mobile Agent Communication in Wireless Networks. In Proc. of European Wireless'99/ITG'99, pp. 211-216, October 1999.

Wooldridge M, Jennings NR (1995) Intelligent Agents: Theory and Practice. In Knowledge Engineering Review, vol. 10, no. 2. pp. 115-152

Johnson DB, Maltz DA, Hu YC (2004) IETF Draft: The Dynamic Source Routing Protocol for Mobile Ad Hoc Networks (DSR).

Karl H, Willig A(2005) "Protocols and Architectures for Wireless Sensor Networks, Wiley.

Kephart J, Chess D (2003) “The Vision of Autonomic Computing,” IEEE Computer, vol. 36, no. 1, pp. 41–50.

Ledezza U, Wetherall D, Guttag JV (1998) Improving the Performance of Distributed Applications Using Active Networks. In: Proc. of INFOCOM, 1998, pp. 590-599.

IBM Press (2003), “Autonomic Computing Initiative,” http://www.autonomic-computing.org.

Neugebauer M, Ploennigs J, Kabitzsch K (2005) Duty Cycle Adaptation with Respect to Traffic.

Perkins C, Belding-Royer E, Das S (2003) IETF RFC3561: Ad hoc On Demand Distance Vector (AODV) Routing.

Serugendo G, Karageorgos A, Rana OF, Zambonelli F (2004) Engineering Self-Organising Systems: Nature-Inspired Approaches to Software Engineering (Lecture Notes in Computer Science).

Smirnov M (2004) Report on FET consultation meeting on Communication paradigms for 2020, Brussels, 3-4 March 2004, Area: Autonomic Communication.

Straßer M, Schwehm M (1997) A Performance Model for Mobile Agent Systems. In: H. R. Arabnia (Ed.): ‘Int. Conf Parallel and Distributed Processing Techniques and Applications (PDPTA’97)’, CSREA 1997 Volume II, pp. 1132-1140.

Subramaniam AP, Gupta H, Das S (2006) Minimum-Interference Channel Assignment in Multi-Radio Wireless Mesh Networks, Technical Report.

Various Authors 2 (2006) http://www.ietf.org/html.charters/manet-charter.html

Various Authors 3 (2006) http://en.wikipedia.org/wiki/P2P

Various Authors 4 (2006) “Autonomic Communication Forum,” http://www.autonomic-communication-forum.org.

Various Authors 5 (2006) “Autonomic Communication Initiative,” http://www.autonomic-communication.org.

Various Authors 6 (2006) http://www.freifunk.net/

Various Authors 7 (2006) http://www.freenetworks.org/

Wikipedia Authors 1 (2006) http://en.wikipedia.org/wiki/Ad_hoc_routing_ protocol_ list

Wikipedia Authors 2 (2006) http://en.wikipedia.org/wiki/Autonomic_computing

Yang B, Liu D, Yang K (2002) Communication Performance Optimization for Mobile Agent System. In Proc. of the IEEE First International Conference on Machine Learning and Cybernetics (ICMLC 2002), pp.327-335. 4-5 November, 2002, Beijing, China.