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Self Configuration Architecture for Carrier Grade Mesh Network (CARMEN)

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Abstract: This paper presents the Self-Configuration architecture design for a multi-radio, multi-technology, carrier grade wireless mesh network (CARMEN). It also describes functions of various system components and their interoperation. The architecture highlights the integration of the novel Abstract Interface (AI) and the IEEE 802.21 extension for media independent radio configuration. The system requirements under two distinct scenarios namely the city deployment and emergency situation are analyzed.

Keywords: Self Configuration, Self Optimization, Node/Neighbour discovery, Wireless Mesh Network

1. Introduction

The EU FP7 CARMEN (CARrier grade MEsh Networks) project aims to design a high capacity, flexible, robust and cost effective wireless mesh network (WMN), which rides on the benefits of multiple radio, multi-technology heterogeneous wireless backbone. Besides provisioning *carrier-grade* triple play services, CARMEN's objectives also include the efficient use of radio resources, support for mobility, broadcast and multicast services and self-configuration.

The Self-Configuration Functionality (SCF) is a key design objective of CARMEN. This is due to the fact that a "carrier-grade" network is not only under constant pressure to rollout new services rapidly; it also needs to ensure that services operate seamlessly 24/7. In general, SCF aims to simplify installation and network start-up, operation and maintenance, and also to enhance global manageability of the network with as little as possible human intervention.

In order to simplify installation, CARMEN Mesh Points (CMPs) or nodes are expected to self-configure or self-adapt their initial configurations, which include the discovery of local node capabilities and neighbouring nodes. Self configuration not only takes place during the start-up phase, but also during regular operation. Due to inherently dynamic radio characteristics of a multi-hop, multi-radio, multi-channel wireless network, continuous reconfiguration and compensation during failures are crucial. For these tasks, CMPs are required to continuously probe the environment and adjust radio parameters such as channel or transmit power.

This paper is devoted to the explanation of the SCF architecture of CARMEN. For this purpose, we first give a short summary of the state of the art in self configuration and specify the most significant improvements targeted by CARMEN SCF. Following this, we analyze the main requirements of self configuration under different scenarios such as a city and an emergency mesh deployment and stress the implications of the differences on the design of the SCF. In Section 4, we present the design of the architecture and its components. Section 5 summarizes a very promising approach adopted by CARMEN, which targets developing a standard enabling intelligent and heterogeneous configuration of wireless mesh network similar to the approach provided by IEEE 802.21. Finally the conclusions are drawn in Section 6.

2. Related work

In the existing literatures, it is easy to find relevant research on self-configuration and topology discovery. For example, [1] adopts a connectivity oriented approach to topology discovery problem in wireless ad-hoc networks. They propose two algorithms to adjust transmission power such that connectivity among mesh points and bi-directionality are guaranteed. Blough et. al. [2] introduce the k-neighbourhood protocol that targets limiting interference using the information of k-hop neighbours. The authors in [3] study the impact of collisions and interferences on the neighbour discovery process in multi-hop wireless networks. [4] studies the node discovery problem in a two node, multi-frequency system, and in ad-hoc, multi-node and multi-frequency system.

On the other hand, channel reconfiguration in WMNs has multiple objectives that consist of minimizing interference while improving the aggregate network capacity and maintaining the connectivity of the network. The existing channel assignment schemes in WMNs can be divided into three main categories — fixed, dynamic, and hybrid — depending on the frequency with which the channel assignment scheme is modified. In a fixed scheme [5, 6, 7], a set of channels are permanently allocated based on a pre-estimated traffic design, while in a dynamic scheme [8, 9], channels are allocated dynamically based on current network conditions. The dynamic scheme usually yields a better performance in terms of interference, throughput and delay at the expense of an added complexity in the control mechanism. A hybrid scheme [10, 11] applies a fixed scheme for some interfaces and a dynamic one for others. Ramachandran et. al. [12] studies the channel assignment problem for multi-radio mesh networks with the aim to assign channels to each of the interfaces in order to minimize interference and enhance the system capacity.

Despite the high number of publications on topology discovery and channel reconfiguration, none of them consider the self configuration problem within a heterogeneous environment in a comprehensive manner. The studies so far work on just homogeneous wireless environment (usually WLAN) and provide solutions to only one of topology discovery or radio configuration problems. However, a mesh network targeting carrier grade services cannot separate those problems, which would otherwise lead to performances far from optimum. In this term, CARMEN provides a unified solution to the self configuration problem. Due to the reasons above, this paper shares the insights on the SCF architecture design for a multi-radio interfaces, multi-technology, carrier grade wireless mesh network.

3. Self Configuration Requirements

CARMEN targets defining a mesh network architecture enabling fast and efficient deployment within different environments. For this purpose, two deployment scenarios have been identified within the CARMEN as more important ones: the city deployment and emergency deployment scenarios. Although the same CARMEN building blocks and functionalities are applicable to both scenarios, the detailed requirements may differ to a large extent. The city scenario mainly targets extending an existing network in case of additional demand for network resources because of an event such as world football championship. The emergency scenario assumes that within a specific area of emergency, most of the infrastructure is destroyed and there are only few gateways with limited capacity that can provide connection to core network. The comparison of the most important aspects of both scenarios is presented in the *Table 1*.

Table 1: SCF Requirements Based on Different Scenarios

Aspect of comparison	**City scenario**	**Emergency scenario**
Network planning	Based on information of existing and stable network. Allow longer period of offline planning	Little or no time for offline planning, require dynamic configuration
Number of Carmen Gateways connected to backbone network	Depending on results of offline planning in terms of capacity and traffic distribution	At least one to provide the access to the backbone as soon as possible
QoS	End-to-end high quality triple-play services, able to support high traffic load	At least text and voice communications
System dynamics	Very low – fixed locations of CMPs, seldom updates	Very high due to likely migration of nodes
Adaptability	Long-term adaptation in order to optimise radio resources usage and traffic load	Fast topology discovery and network formation are desired

4. SCF Architecture Design

The Self-Configuration module (as shown in *Figure 1*) represents the central entity of the CARMEN self-configuration architecture. It comprises different functional blocks such as information collection/capturing, processing, reasoning, distribution (self-description) and radio/network interface configuration, and it is a required component of every CMP. The number and expansion stage of the functional blocks may vary between different types of nodes or even between different nodes of the same type. The design options depend on performance requirements, efficiency or cost-related reasons. In the following subsections we summarize those functional blocks of SCF in more detail.

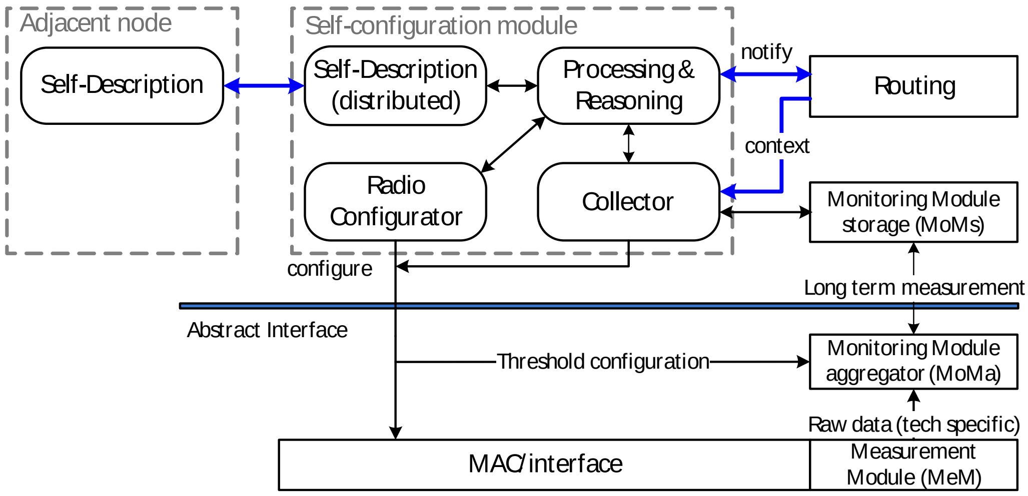

Figure 1 Self-Configuration Architecture

4.1 *Processing & Reasoning Sub-Module*

This sub module is regarded as the brain of SCF. Here, the collected information is processed, consolidated, optionally normalised, and – if the function is present locally – reasoning is performed on the basis of the available context information. Besides the local data gathered via the Collector, the Processing particularly accepts and processes external context information that it receives via the Self-description sub module from other nodes. Different types of algorithms such as linear and non-linear programming, stochastic analysis and evolutionary can be considered to support decision making.

4.2 *Self-Description (Message Distribution) Sub-Module*

This component is responsible for the distribution of context information (i.e. collected information from different sub modules, system modules and interfaces) between the Self-configuration Agents of different CMPs (or nodes). It also supports special monitor components or modules that capture and process this information for network management, information or other purposes (such as service discovery, network surveillance, etc.). Self-Description can be seen as a network-wide, distributed, asynchronous information service that distributes context information of different layers/origins in a general, open, extendible format / representation. One important purpose of this service is to facilitate exchange of information between different CMPs in order to realise an optimal, global or network-wide, configuration. The Self-Description model is based on a mesh extension of IEEE 802.21 protocol and its information elements.

4.3 *Radio Configurator Sub-Module*

This sub module primary handles radio configuration-related tasks. The instructions could originate from either internal sub module such as reasoning or external modules such as routing through processing sub module (in this case processing sub module is functioning as message handler). Radio Configurator generates high-level configuration instructions such as link up/down, change channel/freq, increase/decrease transmit power, change QoS settings, etc, and through the AI interface, these instructions are translated into kernel/technology-specific instructions. This enables the radio configuration tasks to be done in an abstract manner. In addition to taking active instructions above, radio configuration also receives advice not to perform certain configurations that may distort or interrupt operations in other modules. The primitives and protocol messages developed for radio configuration construct link specific mesh extensions of CARMEN IEEE 802.21 mesh implementation.

4.4 *Collector Sub-Module*

The Collector sub module is responsible for the retrieval of information (denoted as 'context information') from different system components/modules. As such, it has interfaces to:

A. **Monitoring Module Storage (MoMs)**, which has been design to process, store and analyze any type of data reflecting mesh network behaviour in a long-term time horizon (timescale of hours and days). The collected data is frequently reported to the MoMs via the AI from the Monitoring Module Aggregator (MoMa). MoMa is responsible for analyzing raw measured data in a timescale of microseconds and seconds, and then performs statistical analysis on the data samples for a given wireless technology. The MoMa receives raw measured data from a dedicated sub-module – Measurement Module (MeM) which resides at the interface driver layer. MeM not only reports the radio parameters of the links on each CMP, it is also helps to detect a new possible neighbour, by means of radio scanning procedure, to which a new link can then be established. Apart of raw data filtering functionality and statistical pre-processing, MoMa also provides continuous threshold based monitoring function via the AI. Based on this, the Collector can set-up desired thresholds values for a given radio link parameter, requesting MoMa to report threshold crossing by sending a proper trigger. The MeM performs monitoring of a variety of radio related link parameters such as: Tx/Rx signal strength, modulation and coding scheme used and Tx/Rx transmission rate, error ratio, channel identifier, bandwidth utilization and link delay.

B. **Routing**, for providing context/status information and retrieving notifications through a direct interface. The information provided to routing comprises a complete, detailed set of all internal context information of mesh topology and established links. In response to this, SCF receives indications about routing specific problems and will attempt to find solutions to those problems by reconfiguring radio parameters. Due to this it is vital for SCF to inform routing function about every taken action which might result in changes of established pipes.

5. Abstract Interface (AI)

As a media independent mesh architecture, CARMEN shares many common attributes with the IEEE 802.21 architecture. The main difference between IEEE 802.21 and CARMEN however is the respective target. CARMEN provides solutions to heterogeneous mesh networks in a media independent manner, whereas IEEE 802.21 focuses only on handovers between heterogeneous technologies. Nevertheless, most of the primitives in IEEE 802.21 are not directly related to handovers but can also be used for different purposes such as managing local and remote radio technologies in a media independent manner. Since such characteristic is also required by CARMEN, CARMEN therefore adopts these IEEE 802.21 primitives whenever possible and even extends some of those with mesh specific functions.

As seen in Figure 2, “Carmen Messaging Service” (CAMS) corresponds to the MIHF of IEEE 802.21. Basically, CAMS aims to extend MIHF of IEEE 802.21 such that besides handover related primitives and messages, it also support mesh related ones. Such an amendment to IEEE 802.21 will make use of just one single interface for realizing handovers, constructing and managing a heterogeneous mesh network.

As mentioned earlier, SCF generates high-level configuration instructions such as link up/down, change channel/freq, increase/decrease power, change QoS settings, etc, and it is the responsibility of CAMS to translate them into driver/kernel/technology-specific instructions. In this figure, both local and remote information exchange is realised over the CAMS. The message types regarding technology specific monitoring information or configuration commands goes through an abstract interface (AI) whereas mesh specific information exchange happens through the module interfaces and corresponding module messages. This enables SCF to communicate with other higher layer modules (SCF, RtF, CHF...) of remote entities. In this way, it is possible to realize topology discovery and formation in a distributed or centralized manner. The box labelled as AI primitives corresponds to MIH_SAP of IEEE 802.21 and the box labelled as module primitives represents the mesh specific higher layer primitives and messages. This separation is crucial within CARMEN due to the fact that module specific primitives of CARMEN are directly related to mesh networks, whereas abstract interface is a more generic interface for managing lower layers. In IEEE 802.21, MIH_SAP includes link events and commands, and the module primitives would correspond to handover commands such as *MIH_Link_Handover_Imminent* or *MIH_Net_HO_Candidate_Query*. A mesh specific example corresponding to such handover related primitives of IEEE 802.21 is *RtF_*

SCF_Deprecate_Links primitive used for informing the routing function about a change in topology.

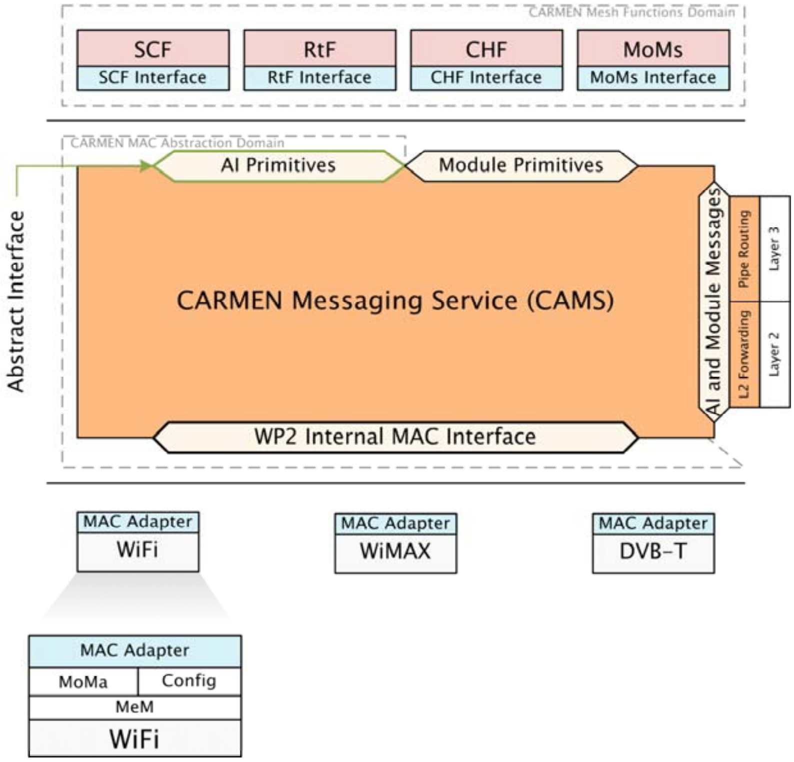

Figure 2 Abstract Interface and CARMEN Messaging Service (CAMS)

One important point here is the fact that IEEE 802.21 does not foresee any direct communication between two remote higher layer entities via MIHF. IEEE 802.21 assumes that MIHF is already aware of the higher layer entity that is responsible for making decisions, such as a handover policy module. Therefore, in case there is a handover message coming from a remote MIHF, the required communication between MIHF and the higher layer entity happens automatically in a vendor specific manner and this is not specified in IEEE 802.21. In the same manner, CARMEN assumes that interface management function is aware of the module responsible for a specific message coming from a remote interface management function (IMF). Nevertheless, for simplicity sake, we prefer to include the names of the module providing the service and the one using it, such as the "*RtF_SCF_Deprecate_Links*" example given above.

Communication between two CAMS instances is performed using the IEEE 802.21 message format. Message transport is realized via CARMEN management pipe whenever possible. If a pipe between the two CAMS instances has not (yet) been established, a L2 ad-hoc mesh routing scheme will be used as a fallback mechanism.

6. Snapshot of Reconfiguration Process

As described above, CARMEN SCF is responsible for many actions within the mesh network for optimizing the network behaviour in an autonomic manner. In *Figure 3*, we provide a snapshot of a reconfiguration message sequence chart (MSC), to give an idea about the process followed as a result of a QoS problem and the types of primitives developed. This part of the MSC assumes that the reasoning sub module of a CARMEN Gateway (CGW) already realized a problem over a set of links based on the input that it gathered through MoMs and decides to react to this problem. After a re-optimization phase of radio parameters, CGW sends *SCF_Reconfiguration.request* message to the responsible CMPs. SCFs of those CMPs then determine that there might be side effects on the existing pipes of the routing function. Here, the CMP's SCF tells routing function (RtF) that some specific links will be deprecated as a result of reconfiguration. This is done using the *RtF_SCF_ Deprecate_Link.request* primitive. After receiving a confirmation from the RtF, the CMP's SCF initiates radio configuration using *AI_Radio_Set_Parameters.request* primitive and informs the CGW about the results of the reconfiguration as *SCF_Reconfiguration response*.

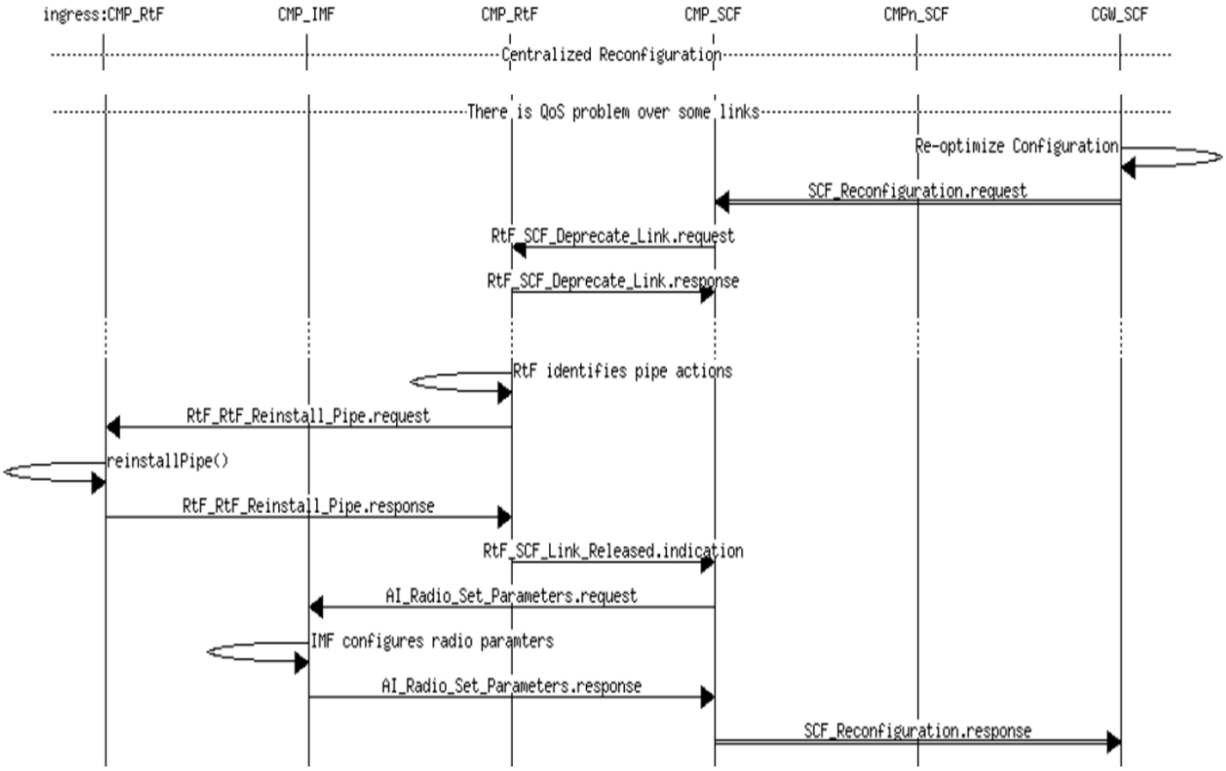

Figure 3 MSC for reconfiguration after a QoS Problem

7. Conclusions

This paper defines a comprehensive self configuration architecture consisting of different sub modules which enable autonomic behaviour within a heterogeneous CARMEN network. In particularly, the AI and the IEEE 802.21 extension for media independent radio configuration make it possible to simplify the construction and management of a large scale heterogeneous mesh networks. Through intelligent reactions to changes in the network behaviours starting from the bootstrapping phase, SCF is able to improve network performance so that the carrier grade targets of CARMEN are feasible. The future work will concentrate on detailed descriptions of the primitives and the protocols and the underlying decision making algorithms utilizing of those primitives and protocols. The proposed architecture will be also implemented and thoroughly tested in real testbed.

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References

[1] Ning Li, Jennifer C. Hou: Localized Fault-Tolerant Topology Control in Wireless Ad Hoc Networks. IEEE Trans. Parallel Distrib. Syst. 17(4): 307-320 (2006).

[2] Douglas M. Blough, Mauro Leoncini, Giovanni Resta, Paolo Santi: The k-Neighbors Approach to Interference Bounded and Symmetric Topology Control in Ad Hoc Networks. IEEE Trans. Mob. Comput. 5(9): 1267-1282 (2006).

[3] E.B. Hamida et.al.: Neighbor discovery in multi-hop wireless networks: evaluation and dimensioning with interference consideration. Discrete Mathematics and Theoretical Computer Science, DMTCS vol. 10:2, 2008, 87–114.

[4] G. Alonso, E. Kranakis, C. Sawchuk, R. Wattenhofer, P. Widmayer: Randomized Protocols for Node Discovery in Ad-hoc Multichannel Broadcast Networks. In Proceedings of 2nd Annual Conference on Adhoc Networks and Wireless, ADHOCNOW'03, p104-115.

[5] A. Raniwala, K. Gopalan, and T. Chiueh, "Centralized Channel Assignment and Routing Algorithms for Multichannel Wireless Mesh Networks," *ACM Mobile Comp. and Commun. Rev.*, Apr. 2004, pp. 50–65.

[6] M. Marina and S. R. Das, "A Topology Control Approach for Utilizing Multiple Channels in Multi-Radio Wireless Mesh Networks," *Proc. Broadnets*, Oct 2005, pp. 381–90.

[7] H. Skalli, S. Ghosh, S. K. Das, L. Lenzini and M. Conti, "Channel assignment strategies for multiradio wireless mesh networks: issues and solutions," *IEEE Communications Magazine,* November 2007.

[8] J. So and N. Vaidya, "Multi-Channel MAC for Ad Hoc Networks: Handling Multi-Channel Hidden Terminals using a Single Transceiver," *Proc. ACM Mobihoc*, 2004, pp. 222–33.

[9] P. Bahl, R. Chandra and J. Dunagan, "SSCH: Slotted Seeded Channel Hopping for Capacity Improvement in IEEE 802.11 Ad-Hoc Wireless Networks," *Proc. ACM Mobicom*, 2004, pp. 216–30.

[10] P. Kyasanur and N. Vaidya, "Routing and Interface Assignment in Multi-Channel Multi-Interface Wireless Networks," *Proc. IEEE Conf. Wireless Commun. And Net. Conf.*, 2005, pp. 2051–56.

[11] P. Kyasanur and N. Vaidya, "Routing and Link-layer Protocols for Multi-Channel Multi-Interface Ad Hoc Wireless Networks," *SIGMOBILE Mob. Comput. Commun. Rev.*, Vol. 10, No. 1. (January 2006), pp. 31-43.

[12] K. Ramachandran *et al.* "Interference–aware channel assignment in multi-radio wireless mesh networks" *Proc. IEEE INFOCOM*, Apr. 2006

[13] S. Schmid, M. Sifalakis, and D. Hutchison. Towards autonomic networks. In 3rd International Annual Conference on Autonomic Networking, Autonomic Communication Workshop (IFIP), Lecture Notes in Computer Science. Springer Verlag, Heidelberg, September 2006.