SUPPORTING CARRIER GRADE SERVICES OVER WIRELESS MESH NETWORKS: THE APPROACH OF THE EUROPEAN FP-7 STREP CARMEN

ARTURO AZCORRA, THOMAS BANNIZA, DAVID CHIENG, JOHN FITZPATRICK, DIRK VON-HUGO, MAREK NATKANIEC, SEBASTIAN ROBITZSCH, AND FRANK ZDARSKY

INTRODUCTION

Wireless mesh networks (WMNs) are a very promising technology to provide an easily deployable and cost-efficient solution for access to packet-based services for metropolitan areas with high population densities. Thus, WMNs may be a key technology in future 4G wireless networks and are currently becoming attractive in situations where it is not convenient to deploy wired backhaul connectivity. For example, it is often impractical to deploy wired infrastructure cost effectively or under tight time constraints. This is particularly true if the deployment is only transient in nature. Another key feature of WMNs is that unlike wireless multihop relay networks, WMNs are not restricted to tree-shaped topologies rooted at the gateway to the wired network and hence do not suffer from the same performance bottlenecks. Instead, any mesh node may communicate with any other one over multiple paths, allowing more efficient utilization of network resources. In contrast to ad hoc networks, WMNs are operated by a single entity, and their components have far fewer restrictions in terms of energy, resilience, and processing power.

The main aim of the Carrier Grade Mesh Networks (CARMEN) project is to design WMN architecture capable of delivering carrier grade triple-play services at significantly lower capital and operational expenditures than comparable wired backhaul networks. There is a particular emphasis on providing a solution for both fast deployment and transient usage scenarios. This goal presents a number of significant research challenges. One key challenge is to reduce the investment required to deploy and operate WMNs. This will be achieved by applying advanced self-configuration and management techniques in all stages from planning to deployment and operation. Currently neither coordinated (e.g., WiMAX-like) nor uncoordinated (e.g., WiFi-like) medium access control (MAC) technologies use wireless resources efficiently for multihop mesh scenarios, making it difficult to provide any guaranteed quality of service (QoS) levels. Therefore, methods for provisioning the QoS required by carrier grade services over coordinated or uncoordinated wireless MAC protocols are a further research topic. In order to develop a robust and long lasting solution, the CARMEN architecture will not be bound to a specific radio technology. Rather, an abstract interface will be defined that can support heterogeneous radio technologies within CARMEN systems.

Although WMNs have been the subject of several research initiatives (e.g., [2–4]) over the last few years, some of which have been developed into products, current WMN solutions fail to meet the stringent quality and reliability requirements of service providers. For this reason an international consortium consisting of network operators, hardware vendors, and research institutions has formed the CARMEN project to investigate and design a WMN solution capable of meeting the requirements of service providers. Specifically the partners involved are: service providers — British Telecom and Deutsche Telekom; vendors — Alcatel-Lucent Deutschland and NEC Europe; and research institutions — AGH University of Science and Technology, Fraunhofer Institute, University Carlos III de Madrid (project coordinator), and University College Dublin.

THE CARMEN PROJECT

The CARMEN Project is a three-year project partially funded by the EU's 7th Research Framework Program and has a total budget of approximately €6 million. The CARMEN project focuses on developing a heterogeneous mesh backhaul solution to provide carrier grade services with greater flexibility and at lower cost than existing solutions. A primary concern for operators is to provide access to typical services via their existing radio access networks, thereby leveraging the capital already invested in these networks. Therefore, any backhaul solution must be capable of providing transport for voice, video, and data services. To achieve high system capacity at carrier grade quality and reliability while preserving flexibility and cost efficiency is a key challenge due to the inherent limitations of WMNs in throughput and scalability. This is a key objective of the CARMEN project. The following provides a detailed overview of the specific CARMEN goals:

1 Create a cost-effective mesh network that supports carrier grade services. This includes the following objectives:
  - Design and validation of an admission control mechanism that considers information from the end user access situation and data about the general capacity available in the mesh cloud in order to decide if new requests should be admitted
  - Development a framework for cross-layer self-configuration and management functions to support flexible wireless mesh deployments and operation
  - Design and validation of network monitoring techniques for heterogeneous wireless mesh networks
  - Development of fixed and dynamic radio planning techniques for heterogeneous wireless mesh networks

2 Support for mobile unicast and broadcast services in a mesh environment. The following tasks are considered here:
  - Design and validation of a multipath routing solution for heterogeneous mesh networks, able to benefit from the abstract interface design and supporting multiple connections to the backhaul network (multihoming)
  - Design and validation of a broadcast/multicast routing protocol and algorithm to provide broadcast services over a WMN
  - Design and validation of an algorithm and protocol to provide network-based mobility management

3 Support for heterogeneous radio access technologies by designing an interface to provide an abstraction of radio-based MAC layers for mesh networks. This involves the following objectives:
  - Development of an abstract interface to allow mesh network components to utilize different radio access technologies (e.g., IEEE 802.11, IEEE 802.16 or DVB) in a technology agnostic manner
  - Development of extensions to the current IEEE 802.11 family of MAC protocols to provide link quality metrics in multihop environments, including algorithms to configure the various parameters in the current

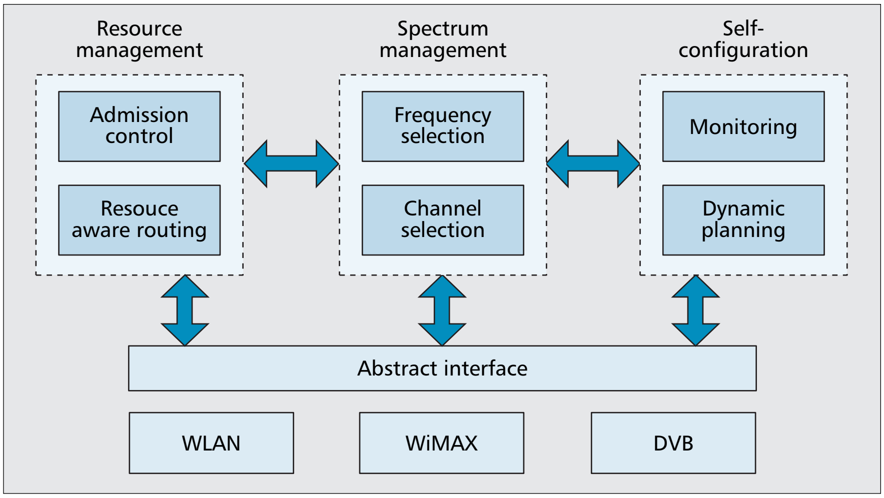

Figure 1. *CARMEN functional components.*

802.11e MAC to provide a level of QoS support
–Development of extensions to the 802.16 MAC to provide link quality metrics in multihop environments, including algorithms to configure the various parameters in the current protocol
–Development of extensions to 802.11 and 802.16 MAC layers to improve the efficiency of MAC layer broadcast
–Development of a distributed scheduling algorithm for 802.16 in a mesh relay context

CARMEN FUNCTIONAL COMPONENTS

The project will develop an architecture for multitechnology WMNs. The main building blocks of the architecture are illustrated in Fig. 1. As shown, the architecture is built around an abstract interface that hides the specifics of the underlying radio technologies from upper layer protocols and provides a common interface to all the functions required for operating the mesh network. The mesh network abstract interface defined in this work is analogous to the role played by IEEE 802.21 for media-independent handovers. The abstract interface functions will assist CARMEN higher layer functions such as routing, resource management for carrier grade services, efficient and flexible spectrum management, dynamic self-configuration and support for mobile users.

Key to enabling the use of heterogeneous radio technologies within the CARMEN architecture is the ability to abstract from a particular network access technology (e.g., 802.11 and 802.16). This abstraction allows mesh management and control functions to handle radio links in a uniform, technology-agnostic manner. At the same time, it allows the project members to experiment with novel medium access control approaches that improve the performance and reliability of single wireless mesh links without breaking compatibility with higher level functions. Hiding technology details behind an abstraction typically incurs a performance cost. An interesting research goal in this respect is to analyze and quantify the performance trade-off of link abstraction and to design functions such that they minimize this cost. This is particularly important for the mesh networking functions studied within the CARMEN project: unicast and multicast routing, capacity handling and mobility management.

Since existing routing solutions are rather focused on a wireless ad-hoc infrastructure, also called mobile ad-hoc network (MANET), the challenge for the CARMEN routing function is how to provide routes that meet the specific QoS constraints of data traffic flows of various traffic classes. Furthermore, current MANET routing solutions come from the assumption that a mesh node is mobile in terms of both its location behavior and availability. To this end, the CARMEN project focuses on developing multipath routing approaches for increasing the utilization of the WMNs resources. The network should have complete control of the traffic flows between each CAP and CGW, allowing for the possibility of using diverse routes for the upstream and downstream flows. CARMEN routing decisions will not only be based on common metrics for weighting the links (e.g., ETX or HELLO message count) but will also use stochastic algorithms for describing the reliability of a link. To fulfill the requirement of an advanced network, routing decisions will be made based on a wide range of metrics from each link.

In order to support carrier-grade services a capacity handling function is used to perform admission control, traffic policing and mapping of data flows to network paths. This will enable control of every data flow inside the WMN; thus CARMEN will prevent any link from over-provisioning. The challenge in this context is to maintain a high utilization of network resources at a low signaling complexity, despite dynamically changing wireless capacities. Further, if the resource capacity of a link is reached, the capacity handling function will have the ability to easily move the traffic flow to an alternate route. The capacity handling and routing module form a dynamic traffic-aware WMN entity that provides the functionality to fulfill the requirement of developing an advanced network supporting carrier-grade services.

The mobility management function needs to work in close coordination with capacity handling, since its handover decisions do not only have to consider the limited resources of the access, but also the resources of wireless mesh itself. It is responsible for providing seamless connectivity to correspondent nodes both inside and outside the mesh network, in the latter case possibly using multiple gateways into the core network. Based on the importance of IEEE 802.21 for mobility support in heterogeneous access networks, this standard will have a significant impact on the design of the CARMEN mobility solution.

The integration of multicast functionality in CARMEN will help to optimize network utilization. In the case when a particular service is being utilized by more than one user at the same time; transmitting common data to a group of receivers only once per physical link optimizes the use of link resources. The CARMEN multicast routing component will be designed to provide QoS-aware 1-to-N group communication and aims to reuse unicast routing and capacity handling mechanism while allowing sender and receiver mobility. In order to alleviate IP multicast traffic load off the CARMEN Mesh, such traffic can be transmitted directly via CARMEN-controlled overlay cells (i.e., DVB/WiMAX) to CARMEN Mesh Nodes in the vicinity of user terminals.

A prerequisite for delivering carrier grade performance is that the underlying mesh network substrate is optimally configured and managed. The CARMEN project is thus also developing tools to support the mesh network planning process. This phase is done prior to deployment and requires information on the radio environment at the deployment site, the service requirements, etc. Multiple radio interfaces are utilized in order to increase the number of available resources or to avoid interferences. During deployment and operation of the network, the self-configuration and management functions ensure that radio and network resources are always optimally allocated. The ability for dynamic self-configuration is one of the fundamental CARMEN requirements as it simplifies installation, administration, and management of the network. It is essential for a newly introduced mesh node to intelligently detect neighbors and their capabilities. The bootstrap phase uses self-configuration techniques to discover the initial network topology. This process creates a logical topology map of the initial network infrastructure, which is provided to the nodes routing module as an initial basis for its operation. These functions allow the system to react to changes in traffic demand and radio environment as well as to network failures.

To make precise and timely decisions, CARMEN's self-configuration and management functions require an efficient measurement and monitoring system, which measures, abstracts, aggregates and analyses vital node, link and network performance data. The reports from the monitoring system are not only crucial for self-configuration, management and planning functions, but also important for the dynamic resource management, such as routing updates or QoS, including admission control decisions.

CONCLUSIONS

CARMEN is a three-year Specific Targeted Research Project (STREP) funded by the European Commission within the 7th Framework Program. The CARMEN access network will complement existing access technologies by exploiting low cost mesh networking techniques, thus minimizing deployment and maintenance costs. The CARMEN architecture introduces an abstraction layer that hides the specifics of the underlying access technology providing an abstract interface on top of which higher layers can be easily developed. This allows for the integration of current and future heterogeneous wireless technologies to provide scalable and efficient mobile ubiquitous Internet access, able to adapt to different environments and user requirements. Following these goals, CARMEN aims to define, study and implement link and technology abstractions, mobility support, and quality of service. The architecture also includes advanced monitoring features that allow for dynamic self-configuration, thereby reducing the installation and operational costs.

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BIOGRAPHIES

ARTURO AZCORRA received his Telecommunication Engineering degree from the Universidad Politécnica de Madrid in 1986 and the Doctor degree in 1989 from the same University. He is a full professor at Universidad Carlos III de Madrid and also the Director of the international research institute IMDEA Networks. He has participated in a large number of European research projects and has published over 100 scientific articles in prestigious international magazines and conferences.

THOMAS BANNIZA received a diploma in communication engineering from the University of Stuttgart, Germany, in 1985. Then he joined the Alcatel Research Center in Stuttgart, now part of Alcatel-Lucent Bell Labs. There he currently works as system design engineer in the area of wireless access networks.

DAVID CHIENG joined BT Malaysian Research Centre in 2006 as a technical lead in broadband wireless research group. Prior to joining BT, David was a lecturer, then senior lecturer in Multimedia University, Malaysia. He received his M.Sc. and Ph.D. in Communication Networks from Queen's University of Belfast, Northern Ireland, U.K., in 1998 and 2002 respectively.

JOHN FITZPATRICK received a diploma in applied electronics from Dublin Institute of technology in 2002, a degree in telecommunications engineering from Dublin City University in 2004 and PhD in Computer Science from University College Dublin in 2008. He is currently a postdoctoral researcher with the Performance Engineering Lab in University College Dublin. His primary research interests are in the area of mobile and wireless networking, QoS in next generation networks and transport layer mobility.

DIRK VON-HUGO received the Diploma and Doctorate degree in Physics from Technical University Darmstadt, Germany, in 1984 and 1989, respectively. Since 1990 he is with Deutsche Telekom where he is currently expert and project manager for next generation mobile and wireless solutions. His activities focus on aspects of seamless communication and intelligent mobile radio access.

MAREK NATKANIEC received the M.Sc. and Ph.D. degrees in telecommunications from the AGH University of Science and Technology, Cracow, Poland in 1997 and 2002, respectively. He is now an assistant professor at AGH University of Science and Technology, working on wireless LANs, designing of protocols, quality of service, and performance evaluation of communication networks.

SEBASTIAN ROBITZSCH received his degree in Media and Communication Technology from the University of Applied Sciences Merseburg, Germany in 2008. Since January 2008 he has been with Fraunhofer-Gesellschaft FOKUS.NET as a research assistant in Sankt Augustin, Germany. His working field focuses on future communication technologies and methods across multiple network layers relating to routing, routing metrics and QoS awareness in wireless mesh networks.

FRANK ZDARSKY received a joint degree in Electrical Engineering and Business Administration from the Technical University Darmstadt, Germany, in 2003 and a Doctorate degree in Computer Science from the University of Kaiserslautern, Germany, in 2008. He is currently working as research scientist and technical project lead at NEC's European Networking Laboratories. His primary research interests are in the area of resource management and performance control for next generation network architectures.