Carrier-Grade Internet Access Sharing in Wireless Mesh Networks: the Vision of the CARMNET Project

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Abstract — **The paper presents the vision of CARMNET – a Swiss-Polish project aimed at investigating "CARrier-grade delay-aware resource management for wireless multi-hop/Mesh NETworks". The project focuses on developing solutions that will motivate telecom operators to reconsider their view on user-operated IEEE 802.11-compliant wireless mesh networks. The project is driven by the vision of networks operated jointly by telecom operators – likely appreciating the CARMNET compliance with their IP Multimedia Subsystem (IMS) infrastructure – and a community of users contributing to and enjoying the pervasiveness of the CARMNET-based Internet access. The project aims at providing, both telecom operators and potential end users, with solutions that will create appropriately strong incentives – technological, functional and economical – for a widespread adoption of CARMNET-like networks within a steadily expanding group of users. Initial results indicate, that despite the originality of the project vision, the preliminary CARMNET system architecture complies with key relevant standards.**

Keywords – wireless mesh networks, user-operated Internet access sharing, IMS, AAA, NUM

I. Introduction

The core idea of the CARMNET project [1] is to make the user-provided Internet access an important alternative to the currently widespread 3G/4G-based mobile Internet access, in particular this provided in the femtocell scenario [2]. The main assumption of the project is that wireless mesh networks [3], while effectively enhanced by the introduction of advanced resource management mechanisms [4][5] and the compliance with the core of the telecom operators' IMS-based Authentication, Authorization, Accounting (AAA) infrastructure [6], may serve as an appropriate basis for a real-world realization of the core CARMNET idea. However, the successful realization of the vision of CARMNET networks – operated jointly by telecom operators and an informal community of Internet access-sharing users – requires facing several scientific and technological challenges that have not been yet completely investigated in the literature [7]. The assumed research tasks have to lead to determination of the comprehensive solution ensuring satisfactory levels of reliability and sustainability of the user-provided Internet access sharing [8]. The research will focus mostly on elaboration of algorithms for reliable servicing of multi-service traffic, with different packet delay tolerance, including algorithms related to: traffic stream classification, packet scheduling, buffer memory management, routing and nodes mobility management.

Targeting the CARMNET objectives implies the need for facing several technological challenges, in particular those related to the compatibility with the key relevant standards, such as Optimized Link State Routing (OLSR) protocol for the reliable multi-criteria routing within wireless mesh networks, or relevant to IMS-based AAA [6] technologies used by telecom operators. Moreover, as far as the long-term sustainability of CARMNET is concerned, some user-centric features are of the key importance, as well. They correspond to functional aspects of a CARMNET network use, such as the user-perceived network utility [5] and the user-friendliness of mobile applications running on smartphones that constitute such a network.

The further part of the paper is organized as follows. In Section II, the project's research motivation is presented. Section III describes the main phases of the project. In Section IV, the exemplary scenarios for CARMNET-like networks are presented and the research areas of the project are outlined. Section V concludes the paper.

II. Research Motivation

The attractiveness of wireless mesh networks to telecom operators, despite a significant research effort that has been put in the last decade [3], remains quite limited. The following issues related to the CARMNET vision may be recognized as potentially postponing the wide adoption of existing wireless networking solutions:

- The lack of integration between the wireless network resource management and the AAA mechanism of telecom operators IMS-compliant networks,
- The lack of carrier-grade systems enabling telecom operators to measure the usage of shared Internet access in wireless mesh networks,
- The lack of solutions enabling end users to request the same level of Quality of Service (QoS) parameters as in 3G/4G networks,
- The lack of integration of the wireless network resource management oriented on the Network Utility

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Maximization (NUM) with 'utility-aware' accounting, in particular in a scenario providing users with 'society-building' incentives similar to those familiar to users of popular Internet file-sharing applications based on the Peer-to-Peer (P2P) protocols [9].

It is worth mentioning that the scope of CARMNET research corresponds to the recent trend of intensive studies on various wireless Internet access sharing methods [7]. The need for CARMNET-like solutions may also be observed in efforts of several commercial Internet service providers, such as FON or Meraki [8]. Moreover, similar scientific projects have been recently conducted, including EU CARMEN [16]. However, to the best of our knowledge, all such initiatives differ from CARMNET in one of its core assumptions: they are based on the use of non-standard hardware.

III. CARMNET WORKPLAN

The CARMNET work plan is divided into three phases. The main goal of the CARMNET theoretical research (Phase 1) is to develop a framework and implementable solutions (i.e., the network architecture, resource management models and algorithms, as well as extensions of existing network protocols) enabling realization of the carrier-grade wireless mesh networks.

During the second phase, the theoretical results will be converted into technically implementable and commercially feasible network protocols and systems, which will be experimentally evaluated in realistic wireless testbeds.

Finally, the key implementation-oriented project outcome will be provided: an IMS-compliant prototype of a wireless network resource management system enabling the realization of 'charging per utility'. This way we hope to propose a solution capable to provide incentives for market-like, self-optimization of the Internet access sharing provided within a community of users.

Selected research topics of the project, as well as the scenarios of CARMNET network usage that will be considered during realization phases of the CARMNET project, are described in Section IV.

IV. CARMNET VISION

The implementation of the CARMNET vision, i.e., a wireless network that allows its end-user to share their network resources, requires defining the usage scenarios and the studies on several research areas implied by such definitions.

A. *Scenarios*

The CARMNET research methodology follows the approach of the user-centered scenario-based design, focused on functional specification of the system in correspondence to the user requirements and activities [10]. Since various wireless network topologies impose different user roles and activities, the main classification of CARMNET scenarios is made according to the types of connections (one-hop versus multi-hop) available in the wireless mesh network. The first scenario represents the case of the fully-connected mesh network (Figure 1), whereas the second scenario allows utilization of multi-hop mesh connections (Figure 2) and imposes the additional role of CARMNET relaying nodes. The figures show the components of the IMS architecture used in CARMNET: Home Subscriber Server (HSS), Proxy – Call Session Control Server (P-CSCF), and Serving-CSFS (S-CSCF), as well as Session Initiation Protocol (SIP) Servlet located at Application Server (AS) [6].

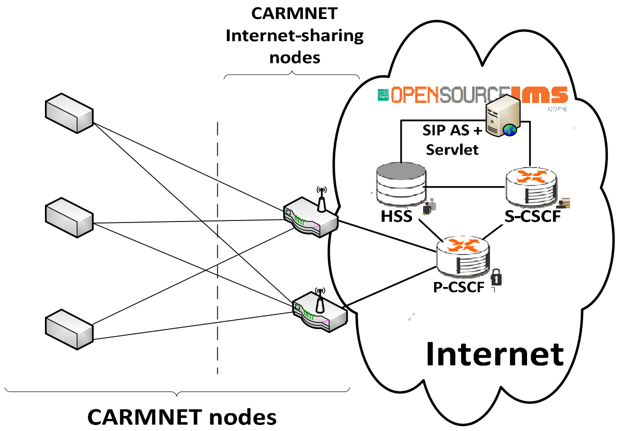

Figure 1. The CARMNET fully-connected mesh network scenario.

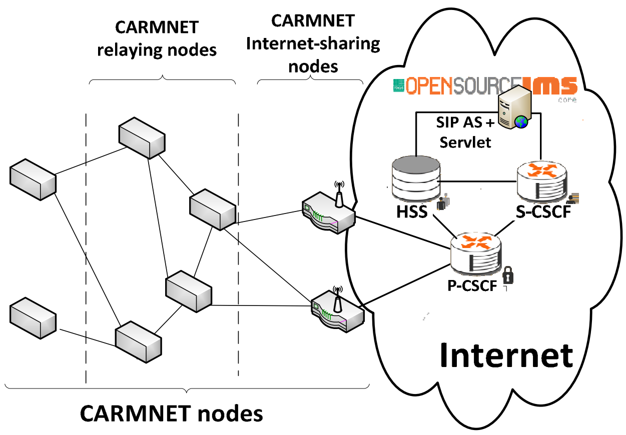

Figure 2. The CARMNET multi-hop mesh network scenario.

In both the CARMNET scenarios the basic network connectivity role is played by the CARMNET Internet sharing nodes, i.e., the network nodes, which may offer the Internet connection to users of other nodes.

B. *Multi-Criteria Routing*

Within the activities related to CARMNET project a new routing protocol (based on the OLSR protocol) that allows for multi-criteria path selection will be proposed. The

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protocol will be capable to build the routing table (at each node), including not only the best path but a set of paths that lead to the specified destination network. The paths in the set will be selected as the subsequent shortest paths to the specified destination, based on one of the *k*-shortest paths algorithms [11][12][13]. The paths will be determined according to main criterion, e.g., delay, and they will include additional criteria (metrics). The additional metrics will be useful in order to choose the best path, that fulfills the criteria for a given traffic stream. The criteria will correspond to the QoS requirements for all traffic classes offered in the CARMNET network. An example of the criteria can be delay, a number of hops, link reliability or link load. Thus, the proposed QoS routing protocol will be able to use different traffic profiles and for each of them will propose the best path, i.e., the path, which fulfills recommended (for the considered traffic profile) QoS values in the best possible way.

The multi-criteria routing is dedicated primarily to the multi-hop scenario, but it can be also used in the single-hop scenario, to select the best CARMNET Internet-sharing node. Additionally, the routing protocol introduced in the CARMNET may be also used as one of the possible methods for mobility management: one or more of the criteria can be used by a mobile node to select the best path (next-hop node) for a traffic stream of a given class.

C. Utility-based Charging

The original CARMNET concept of the utility-based charging is largely based on a synergic combination of the following conceptual components (Figure 3):

- Charging per traffic volume,
- Traffic volume virtualization based on the mechanism of explicit transfer of virtual units that has been proposed as the key element of the Delay-Aware NUM System (DANUM) framework [5],
- IMS-based AAA, realized in the scenario of charging per traffic volume.

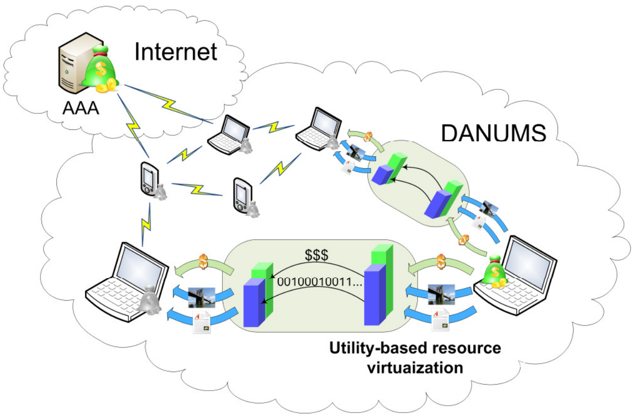

Figure 3. The concept of the utility-based charging as the integration of a DANUM system with an IMS-compliant AAA system.

Typically, CARMNET users are the ones that do not have the direct and acceptably cheap access to 3G/4G network. It is assumed that virtual utility units, after being earned by users sharing their mobile Internet access with other users of CARMNET-based wireless networks, may be spent by these users ('potentially altruistic', i.e., risking the lack of a reward for sharing the Internet connection) for accessing mobile Internet connection shared by other users.

D. Resource Management

One of the key objectives of CARMNET is to integrate IMS-based AAA support with the utility-oriented resource management for wireless mesh networks, in particular the one based on DANUM System (DANUMS) [5][4]. DANUMS is an application-layer system providing a delay-aware indirect flow control mechanism based on a system transporting virtual utility units and a packet forwarding component aimed at providing an approximation of Max-Weight Scheduling (MWS) [14]. The system is the first delay-aware NUM solution interoperable with widely used protocols such as Transmission Control Protocol (TCP), User Datagram Protocol (UDP), Internet Protocol (IP), and 802.11 Media Access Control (MAC) [5].

The other key objective of the CARMNET project in the area of resource management is to elaborate a model of a multiservice state-dependent queuing system with limited queue and state-dependent dynamic resource sharing between individual classes of calls. The advantage of the proposed model will be the possibility to evaluate analytically the average parameters of queues for individual classes of calls, which may prove to be of particular importance in engineering applications, especially in solutions concerning the analysis, dimensioning and optimization of mobile networks.

E. IMS-Compliant AAA Support

The CARMNET architecture assumes the application of an open implementation of the IMS server infrastructure (OpenIMS), extended by the SIP servlet located on the Application Server (AS). The communication between the network nodes and the IMS Server is realized with the use of CARMNET User Agent (a lean SIP client application).

It should be stressed that according to the vision of CARMNET, the standard session management functionalities provided by IMS core servers are used in a non-typical way - for the management of user-shared Internet access sessions (so called "CARMNET sessions") rather than, e.g., for the management of VoIP sessions. On the other hand, the standard AAA functionalities provided by IMS core are extended by additional CARMNET-specific features of utility monitoring that enable utility-based charging. These additional functionalities are provided in an IMS-complaint way, as a result of an implementation of SIP servlet and a special "CARMNET over SIP protocol" used for exchanging the information for the purpose of the utility-based charging. What is specific

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for CARMNET is that the IMS infrastructure is used to manage users profiles and to store the configuration of end-users' utility functions.

F. Multi-Testbed Experimentation

The project aims at achieving a significant experimentally evaluated improvement in wireless network resource management. The experiment evaluation will involve both the effectiveness of network resource management systems and user-oriented network reliability.

In order to make the experimentation more reliable and effective, a special evaluation methodology and experiment description framework will be defined. A set of software components enabling an automated, highly controllable experimentation evaluation of IMS applications realized in wireless multi-hop networks will be developed.

The project outcomes will be evaluated in several experimental scenarios of infotainment and conversational services for networks of wire-line infrastructure limited to Internet access points, in wireless fully-connected mesh network and multi-hop network scenarios, as well as in mobility-oriented scenarios.

CARMNET solutions will be tested in several realistic testbeds, in particular in the ones located at CARMNET partners facilities (including the wnPUT testbed [4], and the SUPSI [1] testbed). Additionally, experiments in large-scale wireless testbeds, i.e., DES-Testbed [15] and NITOS testbed [4], are planned, as well as experiments performed within the facilities of a telecom operator.

V. Conclusions

In our opinion, CARMNET is a project worth a significant interest of researchers working in – so far rather distinct – areas of wireless mesh networking and IMS-based session and user management. On the other hand, the practical importance of the project research objectives seems to be in line with the recent trend of deploying wireless Internet access sharing by commercial service providers and telecom operators. The project is aimed at ensuring incentives for both telecom operators and potential mobile Internet end users for a fast and widespread adoption of CARMNET-like networks.

Although, for the time of writing this paper, the project is at an early stage, its initial results are already encouraging. In particular, despite the originality of the functional and the technological assumptions with regard to the CARMNET system, the initial system architecture design seems not to compromise the compliance with key relevant standards, such as OLSR, and IMS core standards.

We believe that, largely thanks to the originality of the CARMNET vision and the appropriateness of the experimentation-oriented methodology, CARMNET will provide outcomes of both the purely scientific impact and the practical added value.

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