Image Processing & Communication, vol. 18, no. 4, pp.43-56
DOI: 10.2478/v10248-012-0092-1

SIP-BASED AAA IN DELAY-AWARE NUM-ORIENTED WIRELESS MESH NETWORKS

PAWEŁ MISIOREK[1] PRZEMYSŁAW WALKOWIAK[1] STANISŁAW KARLIK[1] SALVATORE VANINI[2]

[1] Institute of Control and Information Engineering, Poznan University of Technology, Poznan, Poland
{pawel.misiorek, przemyslaw.walkowiak, stanislaw.karlik}@put.poznan.pl
[2] Institute for Information Systems and Networking, University of Applied Sciences and Arts of Southern Switzerland, Manno, Switzerland
salvatore.vanini@supsi.ch

Abstract. A growing number of mobile nodes that require Internet access is observed. These nodes may be organized in a wireless mesh network in which some of the nodes may serve the access to the Internet and relay other users' traffic. Such a vision, however, causes the need for carrier-grade reliable Internet sharing solution. This paper presents a CARMNET-XML protocol, which enables to provide Authentication, Authorisation and Accounting AAA functionalities in wireless mesh networks managed by the Delay-Aware Network Utility Maximization System (DANUMS). The presented solution is a part of a CARMNET system, which integrates the utility-oriented resource allocation provided by DANUMS with the IMS architecture. The system allows users to access Internet with a given quality without the need of extending the operator's infrastructure. Moreover, we define the scenario of the system application involving the use of the proposed protocol that has been experimentally evaluated in a wireless testbed environment.

1 Introduction

More and more mobile devices need Internet connection to be fully functional. Providing constant, sufficiently high quality services for those devices is a challenge not only because of problems inherent in wireless communication (such as interference and obstacles) but also because of the fact that sufficient transmission quality differs largely between usages. Waiting a few more minutes for a file transfer to complete is inconvenient but acceptable, whereas a tearing and garbled VoIP connection is simply useless.

Even in a scenario when our own wireless home network is not available (or of poor quality), as a result of current proliferation of wireless devices there is a high chance that there are several other WiFi-capable devices within our WiFi range. One of them might have enough network resources (due to the better signal, using other provider, or even using wired connection) to satisfy the needs of other nodes. By connecting nearby wireless devices into a mesh network and allowing them to share their network resources, the overall availability and quality of Internet access could be increased. For this idea to work, there must be a strong incentive to share resources by users. To properly reward the user that shares the Internet access, we need to measure and record the value of the services she/he provided. Since usability is to be maximized, this value depends not only on the amount of data transferred (i.e., the flow's rate) but also on other flow characteristics which influence the user-perceived utility (e.g., the end-to-end delay). What user earns by sharing her/his resources can be used to access resources provided by others.

This paper presents a solution, referred to as a *CARrier-grade delay-aware resource Management for wireless multi-hop/mesh NETworks* (CARMNET) system [8], which is aimed at providing the functionality of reliable Internet sharing. The idea of the CARMNET system involves the integration of a Delay-Aware NUM (DANUM) System [17] and an IMS infrastructure [1]. The DANUM model itself was proposed in [16, 17]. The CARMNET system vision was introduced in [8]. The preliminary model of communication between the DANUM subsystem and the IMS was proposed in [19]. The new contribution of this paper focuses on the description and operational analysis of the novel CARMNET-XML protocol and consists of (i) the definition of the CARMNET-XML protocol, (ii) the description of its implementation and role in CARMNET system operation, (iii) the description of the CARMNET system use cases, and (iv) the experimental evaluation of the proposed protocol operation provided based on experiments conducted in a real-world wireless testbed.

The presented solution allows to solve the last mile problem and enables the introduction of a new business model where users may benefit from relaying data. On the other hand, telecom operators may increase their network utilization while serving Internet sharing management and AAA services.

2 Related work

The problem of integrating the carrier-grade IMS platform with wireless networks, with the aim of widening the area of Internet access provided by telecom operators, is still intensively investigated. Most of already proposed solutions focus on enabling the mobility of user devices and providing Quality of Service (QoS) for IMS services like voice and video calling. The authors of [11] propose an integration of the Mobile IP standard [13] (enabling the seamless handover between networks) and the IMS infrastructure allowing to automatically trigger the registration procedure in IMS services in the case when user changes location. In [7], a mechanism for secure access based on SIP and IMS in an integrated UMTS-WLAN environment is described.

A more complex solution is proposed in [5], in which, in addition to providing seamless and transparent mobility, the goal is to maintain Quality of Service of the ongoing session in WiMAX and UMTS networks. However, the session QoS is verified only against the throughput which can be achieved in the preferred connection. In [3], authors present a solution for seamless terminal mobility that combines a multi-homing protocol (SHIM6) to manage access network change, with the IMS architecture, which allows the establishment of multimedia session with QoS. A SIP proxy is implemented at the terminal side to manage session negotiation. SIP is used exclusively for handoff management.

The authors of [6] propose introduction of QoS and AAA into carrier-grade mesh networks as a result of using the additional IMS infrastructure components like Resource and Admission Control Subsystem (RACS) and Network Attachment Subsystem (NASS). The RACS supports the resource reservation methods, admission control, and policy decisions, whereas the NASS supports automatic device configuration and network access control. Both the proposed subsystems and IMS infrastructure enable AAA and QoS functions for network clients, which have to successfully perform the SIP registration procedure to get access to the network and other provided services.

To the best of our knowledge, none of the proposed solution tries to incorporate flow utility estimation grounded on Network Utility Maximization (NUM) framework [10], as it is done in our proposal.

3 CARMNET application scenario — Internet sharing based on earning and spending virtual units of utility

In this section we present the application scenario aimed at demonstrating the goals and advantages of the CARMNET system. We start from description of benefits provided by the system and then we present a real-world scenario in which the CARMNET system may be applied.

The more technical specification of the scenario aimed at showing how the system delivers the AAA functionality by means of the CARMNET-XML protocol is presented in Subsection 5.3. The last part of the scenario, which involves the system functions using the CARMNET-XML protocol, was used as a basis for experiments presented in the Section 6.

3.1 The benefits from using the CARMNET solution

One of the goal of the CARMNET system is to make the telecom operator IMS services effectively available to users of wireless mesh networks. As a result of integration of the carrier-grade AAA with the NUM-oriented resource management, the system enables the application of utility-based charging based on the denarii [17] (i.e., the virtual units of utility) calculation functionality of the DANUM subsystem, which may be used as a market-like regulator for utility- and reliability-oriented resource allocation.

The presented scenario is aimed at illustrating the telco-oriented application of the CARMNET system supporting the relaying node mobility and leading to widening of the area of operator's services availability without increasing operator's costs. In this scenario users may be seen as partners maintaining the last hops of a network by themselves and offering the Internet connection. Moreover, the solution is a win-win operator-user collaboration, in which users may be also beneficial by earning and spending the virtual units of utility.

The CARMNET system goals include providing an access to the Internet in places without (or with very weak) WiFi signal from the static infrastructure. It may be particularly useful in metropolitan networks, where extending range by means of static infrastructure can be expensive. In contrast, the CARMNET system, as a distributed and dynamic solution based on the wireless mesh network paradigm, employs wireless nodes to extend the range of network.

3.2 The scenario description

The application scenario is described from the perspective of the CARMNET system user (referred to as Alice) and is divided into two steps: in the first one, Alice earns virtual money and in the second one, she spends the money. The scenario is illustrated in Fig. 1.

Step 1: Providing Internet to other users. Alice is an owner of a mobile device. When she is in her home she usually uses her home wireless network in order to connect to the Internet. Having gained knowledge about the CARMNET system, she has registered to it via a simple registration process by means of IMS subsystem available

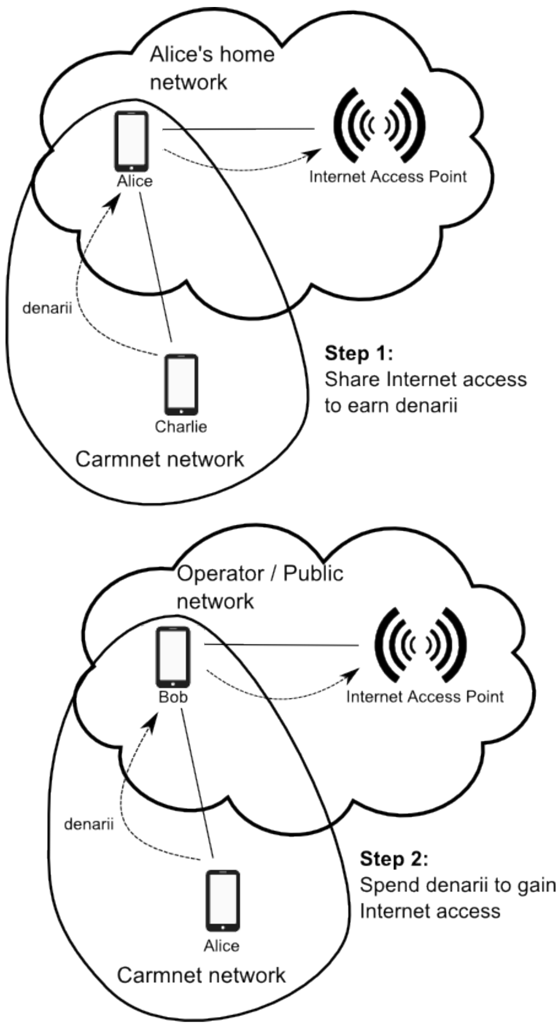

Fig. 1: The application scenario: sharing the Internet access.

via the Internet access point [19]. As a CARMNET user she may be recognized by other CARMNET users (e.g. by Charlie, see Fig. 1) and may start to serve as a relaying node, sharing the Internet access. She may share the Internet both when she is using her home wireless network (to users which have currently no access to the Internet) and when she uses some public network (e.g., to users, which are outside the network range, but have good connection with the Alice mobile device). When forwarding Charlie's traffic, Alice has earned some amount of virtual currency units (i.e., denarii). The number of denarii she earned is calculated according to information provided by the DANUM subsystem. The denarii may be additionally recalculated within operator's IMS subsystem in order to exchange it to the operator's 'real' accounting units.

Step 2: Using Internet shared by other CARMNET users. Alice is on holidays, and she needs the Internet connection in order to check the train schedule. She is not able to access any network providing Internet connection, but fortunately she has noticed Bob as other CARMNET node accessible in her wireless device range. She has been recognized by Bob's device as a CARMNET node, therefore she is able to connect to Internet using Bob's device as the relaying node. Since Alice is recognized by CARMNET IMS subsystem (available by means of Bob's Internet connections) as a user who has already earned some denarii, she is able to spend part of them using the Internet access shared by Bob. At the same time, Bob earns denarii, and may share the earned number of denarii with the operator (the part of the user-operator win-win strategy). This step of the scenario is used as the basis of experiments presented in Section 6.

4 The CARMNET system

The idea of the CARMNET system was proposed in [8]. CARMNET enables its end users to share their resources, in particular to share the Internet access. The system architecture is illustrated in Fig. 2. As it can be seen from the picture, some network nodes (referred to as the CARMNET Internet-sharing nodes) offer the Internet connection to users of other nodes. The Internet sharing is optimized as a result of the application of the utility-aware resource allocation subsystem, which allows to compare the utility of flows with different requirements with regard to end-to-end delay and throughput [17].

On the other hand, the CARMNET system uses an enhanced IMS architecture to provide the session and user management. The CARMNET idea is to combine the

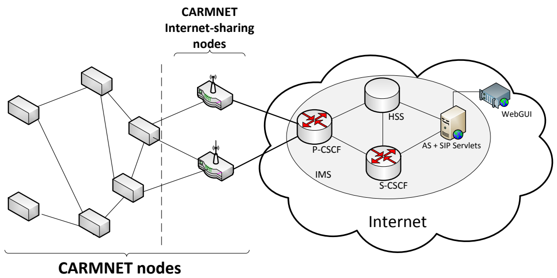

Fig. 2: The CARMNET system general architecture.

unique features of utility-aware flow control and resource allocation (provided by DANUMS [17]) and the AAA functionality (provided by the IMS subsystem) in order to enable the utility-based charging, in a way that encourages mobile users to share their Internet connection and which is, at the same time, suitable for telecom operators. In the next sections, we describe the main components of the CARMNET system.

4.1 IMS infrastructure reuse

The SIP (Session Initiation Protocol) is a standard in telecom business. IMS systems are already a crucial part of the telecom infrastructure, thus it is easier to introduce new features based on SIP than to implement new protocols. The IMS subsystem may be enhanced with new features by implementing new servlets running on an application server.

The IMS/SIP infrastructure provides out-of-the-box functionalities such as user authentication and authorization that may be reused in the CARMNET system. The SIP User Agent (SIP UA) applied in our solution is used only for transferring additional data needed by CARMNET wireless nodes by means of a SIP message schema. Therefore, a very thin client implementation is needed. The biggest benefit of using SIP in the DANUM-based solution is the fact that in such a case the impact on the operator infrastructure is minimal [18]. The migration form non-DANUM- to DANUM-bases systems does not require large investments in the infrastructure.

4.1.1 SIP User Agent

The integration of the DANUM LKM (DANUM Loadable Kernel Module) with the IMS infrastructure is a difficult task because of the lack of the SIP protocol implementation in the Linux kernel-space. Therefore, a new SIP User Agent (SIP UA) component running in the user-space was developed. The main task of the SIP UA is to provide asynchronous communication channel between IMS and DANUM LKM. The communication between SIP UA and LKM is realized using the Netlink protocol, whereas for the purposes of the communication between SIP UA and IMS, the CARMNET-XML protocol encapsulated in the SIP protocol is used.

4.1.2 SIP servlet

Another requirement that has to be met by the IMS is to handle the CARMNET-XML protocol. Therefore, at the IMS side, a SIP servlet was implemented and deployed on the application server. The main responsibility of the servlet is to manage user profiles in the CARMNET network. After the network connection establishment, each client gets authentication and authorization by the IMS module, and registers in the SIP servlet. Once the CARMNET Internet session is started, each node reports to the SIP servlet about what type and how many traffic it served.

4.2 The DANUM subsystem

The DANUM System (DANUMS) [17] is aimed at optimizing resource allocation in wireless networks according to a delay-sensitive version of the Network Utility Maximization model [10]. Similar solutions based on a standard rate-oriented NUM are Horizon [14], wGPD [4] and DiffQ [21]. (DANUMS) is based on NUM model [10] but it differs from its original rate-oriented version since it is aimed at serving heterogeneous traffic with different rate and delay requirements.

The main task of the Delay-Aware Network Utility Maximisation (DANUM) model is to provide an optimal packet scheduling policy, with respect to the maximisation of the network users' satisfaction throughout maximisation of the flows' utility, which depends both on rate and delay.

The relation between measurable flow transmission quality parameters and its utility is modelled by means of a utility function. Each utility function corresponds to flows of a given type, or more precisely, to flows with specific network requirements. A virtual queue is defined as a product of flow's packet backlog level and a *virtual price* of a single packet. Packet's virtual price is a value of the derivative of a utility function assigned to the flow. The utility function depends on both flow rate and delay. It plays an important role in packet scheduling as well as influences the cost of CARMNET network usage. The details concerning the (DANUM) and its implementation can be found in [16, 17, 20].

4.3 Flow Classification Framework for DANUMS

In order to assign the correct utility function to a given flow, the DANUMS uses the flow classification framework described in [20]. This subsystem allows to provide a fine-grained flow classification, which is a cascade of simple filters. Flow's properties are checked against rules defined for each of the defined filters, where each rule is a pair composed of filter-specific constraints and a flow type. The result of the classification is an information containing the flow type assigned to the matching rule. In the case of a failure of each of the filters, a default utility function is assigned to the flow — for such flows a constant virtual price for each packet is assigned.

5 Overview of the CARMNET-XML protocol

The CARMNET-XML protocol is used to transfer information about currently served user profiles (their utility functions parameters, current user denarii balance, etc.), as well as information about neighboring nodes and reports on handled traffic. It uses SIP-based built-in SUBSCRIBE/NOTIFY [15] mechanism to pass XML messages between SIP UA (located on the wireless node) and SIP Servlet (located at the IMS side).

5.1 CARMNET-XML protocol

The protocol involves 5 types of XML messages: GetProfile, ProfileData, GetNeighbour, NeighbourData, and TrafficReport. When SIP UA needs some data, it sends a SIP SUBSCRIBE request with appropriate XML 'Get' message in its body. SIP Servlet replies with SIP NOTIFY message containing requested data as a XML 'Data' message in the body. At the beginning of operation, SIP UA subscribes for its user profile. When SIP Servlet receives SUBSCRIBE request from a previously off-line user, it updates the list of currently on-line users and subscribes for traffic reports from this user. At this moment, SIP UA can send SIP NOTIFY requests containing TrafficReport messages.

SIP Servlet maintains list of currently on-line users as well as SIP-ids-to-IP mappings, allowing proper handling of messages in which CARMNET nodes are identified only by IP.

5.2 CARMNET-XML protocol messages

GetProfile

- IP: address of the node whose profile is requested

ProfileData

- SIPid

- CurrentIP
- Balance: Amount of virtual currency units available
- UtilityMatch: Contains information about utility function type, its parameters and its assignment to a flow class.
- Standing: The additional value which represents the profile reliability (i.e., the user reputation).

GetNeighbours

- IP: address of the node whose limited profile is requested

NeighbourData

- SIPid
- CurrentIP
- Standing: The value which represents the profile reliability (i.e., the user reputation).

TrafficReport

Each TrafficReport message contains one or more reports about served flows. Each flow is described by:

- SourceIP
- DestinationIP
- Cost: expressed in denarii
- FlowID

5.3 The description of the CARMNET-XML protocol application in the CARMNET session

The functionality and application of the CARMNET-XML protocol is described by means of the second step of the scenario presented in Subsection 3.2.

Bob is connected to the static infrastructure and registered to the CARMNET network by means of the CARMNET SIP User Agent component logged to the operator's IMS subsystem. As a result, he has got possibility to use the CARMNET Internet sharing functionality.

The Alice's mobile device, with only Bob in its range, follows the same process of registration as Bob did. After the registration, Alice starts to use the Internet connection provided by Bob. During the connection, Bob, as the CARMNET Internet sharing node, earns denarii according to the utility of forwarded traffic. Simultaneously, the denarii are spent by Alice.

All information on generated and forwarded traffic are reported to the operator by means of the CARMNET SIP UA, and the balance of both Alice's and Bob's account is updated. The amount of transferred denarii is computed taking utility of served traffic into account, by means of the DANUM system. This approach enables users to pay only for what they get. The denarii earned by Bob can be spent to gain access to the Internet or other services provided by the network operator, whenever Bob will need it and he is able to connect with another CARMNET Internet sharing node.

This sequence of actions may be described in detail by means of the CARMNET-XML protocol messages. The illustration of a message sequence chart is presented in Fig. 3.

As mentioned earlier, firstly Bob has to connect to the CARMNET network. This is achieved by connecting to the IMS server using the integrated SIP UA. Two messages are sent, (i) the SIP REGISTER — in order to perform authentication and authorization, and (ii) a subscription of the CARMNET-XML GetProfile — in order to get the user profile. SIP Servlet reacts to a new user's registration by subscribing for his traffic reports. It is important to make the time of registering and retrieving profile data as short as possible. One of the experiments presented in Section 6 is focused on this issue.

Alice has to repeat the same process as Bob in order to connect to the network. After registering and subscribing of the profile, the OLSR routing protocol [17] discovers a

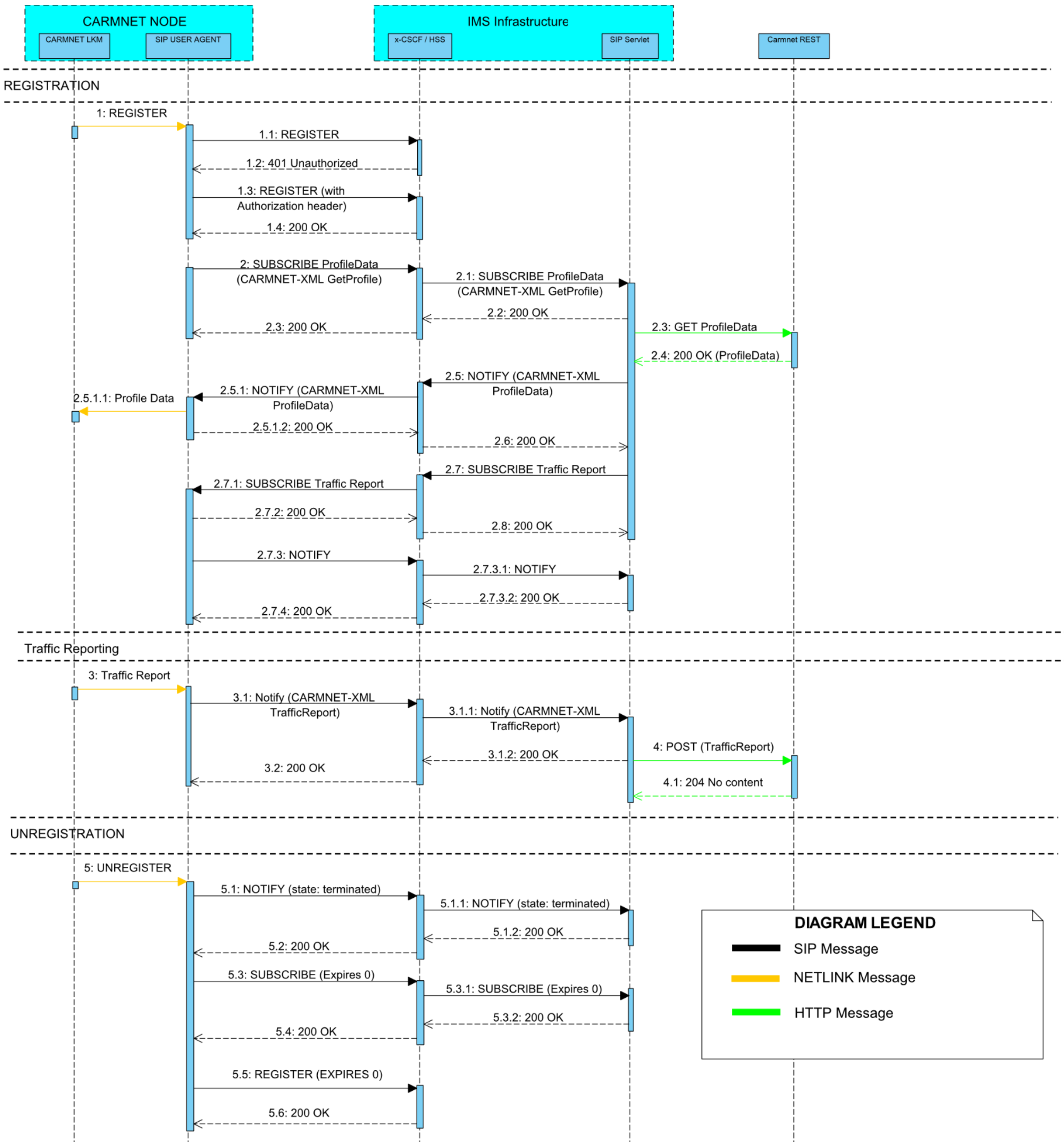

Fig. 3: Message sequence of user registration, reporting traffic and unregistration.

new neighbor on both Bob and Alice devices. At this moment, the SIP UA subscribes the information about the available neighbors by means of the CARMNET-XML GetNeighbour message. This procedure is executed on both nodes (the Bob one and the Alice one): Bob is subscribing the profile of Alice and vice versa.

From this moment, sharing of the Internet access by Bob is possible. The transmission is controlled by the CARMNET LKM subsystem, which performs routing and scheduling operations based of the solution of the DANUM optimization problem. The CARMNET LKM (with support of the extensions of the OLSR routing protocol) computes utility of the flows and the amount of denarii needed to serve the traffic properly. Periodically, each client reports amount of traffic and denarii (which were sent or forwarded) by means of the CARMNET-XML ReportTraffic message sent to the IMS server. At the IMS server, data are validated against each other and, in consequence, the status of denarii balance of each user is updated.

6 Experimentation

6.1 Testbed

A wnPUT testbed [12] have been used to perform experiments. The architecture of the wnPUT testbed was inspired by the Distributed Embedded System Testbed (DES-Testbed) [2]. Currently, our testbed consists of about 20 PC-class machines, equipped with wired and wireless interfaces. The purpose of the wired network is to provide experiment management interface. On the other hand, the wireless connection is used for experiment execution purposes. Each node of the testbed runs a Linux distribution.

The testbed allows for an easy and automated experiment execution. It handles parsing of the experiment description files, setting up wireless network, configuring topology, executing specified commands and, finally, gathering results. Experiments are described using the scenario files written in XML. The syntax of those files is an extension of the DES-CRIPT [9] language used in (DES-Testbed) [2]. The unified format of experiment description files has many benefits such as portability and expressiveness, as well as allowing the experiments to be performed on different testbeds. The phases of experimentation has been defined in [2, 12]. The status of performed commands and the (DANUMS) LKM is acquired in real-time by means of `rsyslogd` and visualized by a monitoring system in order to make the result analysis easier.

Tab. 1: Overhead experiment, single flow results (average values taken from 3 executions).

node	metric	value	Overhead
A1	packet count	109169.67	-
	kilobytes	109599.90	-
	SIP packet count	80.67	0.07%
	SIP kilobytes	46.33	0.04%
A2	packet count	109129.33	-
	kilobytes	109555.50	-
	SIP packet count	86.00	0.08%
	SIP kilobytes	49.68	0.05%

6.2 Experiments

Three experiments were conducted in order to evaluate the integrated solution operation, focused on the analysis of the CARMNET-XML protocol overhead, the dead-time (i.e., the time needed to get the user profile information) measurement, and the evaluation of reporting reliability, respectively.

6.2.1 Protocol overhead

We performed three experiment variants in order to measure the average overhead which was introduced by the CARMNET-XML protocol in different network configurations. The number of nodes used and network topology vary between experiment variants. Two types of measurements were performed at each node of the network,

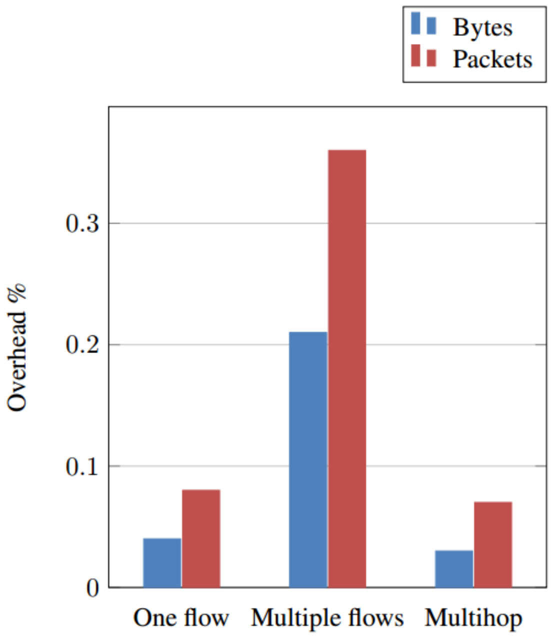

Fig. 4: Protocol overhead

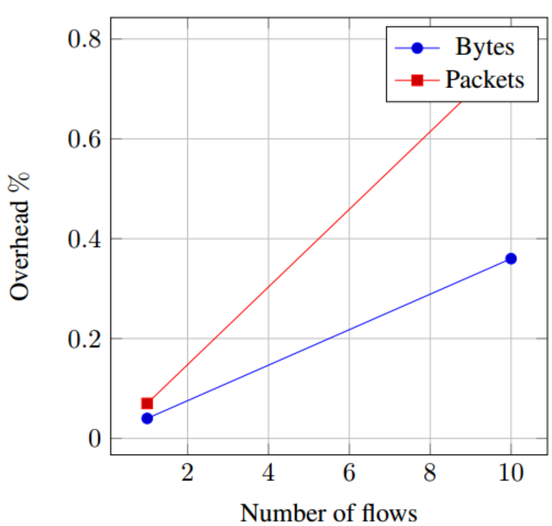

Fig. 5: Relation between overhead and a number of flows

Tab. 2: Overhead experiment, 10 flow results (average values taken from 3 executions).

node	metric	value	Overhead
A1	packet count	71310.33	-
	kilobytes	105218.25	-
	SIP packet count	97.67	0.14%
	SIP kilobytes	68.30	0.06%
A2	packet count	71556.33	-
	kilobytes	105222.24	-
	SIP packet count	550.33	0.77%
	SIP kilobytes	377.44	0.36%

Tab. 3: Overhead experiment, multihop flow results (average values taken from 3 executions).

node	metric	value	Overhead
A1	packet count	69270.00	-
	kilobytes	102224.63	-
	SIP packet count	73.67	0.11%
	SIP kilobytes	51.91	0.09%
A2	packet count	134570.67	-
	kilobytes	198642.52	-
	SIP packet count	77,00	0.06%
	SIP kilobytes	54.21	0.03%
A3	packet count	133568.33	-
	kilobytes	197160.61	-
	SIP packet count	79.33	0.06%
	SIP kilobytes	55.76	0.03%
A4	packet count	69178.67	-
	kilobytes	72821.19	-
	SIP packet count	38.00	0.05%
	SIP kilobytes	27.55	0.04%

the first one focused on the overall number of bytes and packets received and sent by the node, and the second one taking into account only the packets corresponding to the CARMNET-XML protocol application. In the first experiment variant, 2 nodes (A1 and A2) exchanged 100MB of data among themselves in a single TCP flow. This experiment gives us a baseline, which can be used to compare other results. The second experiment configuration also involved 2 nodes and transfer of the same amount of data, however, this time the transmission was divided into 10 separate TCP flows, 10MB of data each. This, combined with the previous result, gives a clue about how the over-

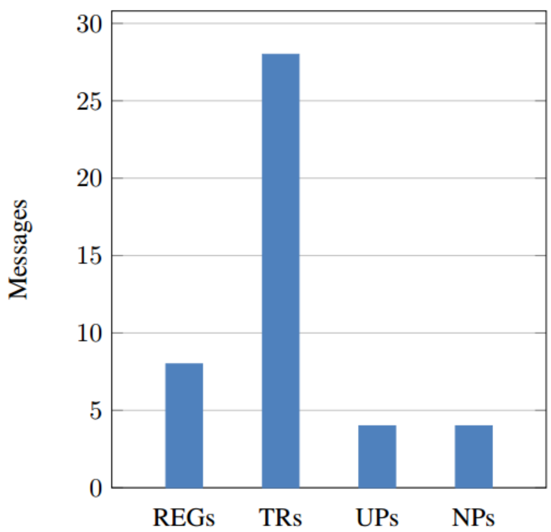

Fig. 6: Message type distribution

head scales with the number of simultaneous flows. The last configuration involved 4 nodes arranged in a linear topology. The goal of this configuration is to analyze how the use of multihop transmission affects the protocol overhead. 100MB of data were transmitted from node $A1$ to node $A4$ via nodes $A2$ and $A3$. The experiment was executed three times for each configuration. The presented results are averaged over these three executions.

Figures 4, 5, and 6 and Tables 1, 2, and 3 present the percentage of the overhead in the overall traffic per each node for each experiment configuration. It may be observed that the overhead grows more with the number of served flows than with the number of hops in the multihop transmission. For each of the presented experiment execution the overhead generated by CARMNET-related control traffic is much less than one percent of the overall traffic.

The last chart (Fig. 6) shows the distribution of the CARMNET-XML traffic in one of the experiment configuration grouped by the types of messages: registration (REGs), traffic reports (TRs), user profiles (UPs), and neighbor profiles (NPs). As a result of the message caching, the contribution of transmitting user and neighbors profiles is marginal in comparison to the traffic reports, which are transmitted periodically. The frequency of traffic reporting could be controlled with respect to activity of the user (amount of transmitted traffic).

Tab. 4: Dead time measurement results (provided in milliseconds).

	ex1	ex2	ex3	mean
Time from the SIP-UA start to profile retrieval	297	431	278	335.33
Classification function call	2	2	2	2
Sum	299	433	280	337.33

6.2.2 Dead-time measurements

For each CARMNET node, it is crucial to know the utility function of each served flow. However, the utility functions are stored on the server behind the IMS system. Therefore, at the beginning of the flow, each node has to acquire the appropriate user profile and its utility functions from the server. This operation may take some time, during which the traffic is served according to the default classification. Unfortunately, that dead time cannot be avoided, however it can be minimized. The reduction of dead time can be achieved by caching the completed user profile, if at least one of his flows has been served.

The dead-time measurement experiment has been executed three times. The results are presented in Tab. 4.

The results contain the time between the start of SIP user agent and retrieving the user profile (the operation which is performed only once at the beginning of node operation in the CARMNET network, which consists of registration and getting the profile steps), and the time of call for the flow classification function (the operation which is performed at the beginning of each flow transmission). It may be observed that the operation of getting the profile takes much more time than the operation of flow classification. This is the reason why the user profile caching was applied.

6.2.3 Traffic reporting and charging accuracy

One way to check the overall accuracy of AAA functionality (mainly traffic reporting and charging) is to compare traffic actually sent with the traffic reported by nodes separately. In general, CARMNET-XML reports contain information on the number of virtual utility units (i.e. denarii). This number depends both on the number of bytes sent and the virtual price of a given flow. Since we are able to determine the number of bytes actually sent by checking it on the device of a given node, we additionally report the number of bytes for the purpose of this experiment. This way, we evaluate the correctness of reports by comparing the overall number of bytes actually transmitted in the given experiment execution with the overall number of bytes reported by means of CARMNET-XML TrafficReport messages. Differences in those values might result from (among others) dropped packets and retransmissions.

In the presented experiment (which was executed three times), a fixed (128 MB) amount of traffic was sent across a network consisting of 4 CARMNET nodes, arranged in a linear topology. Node $A1$ is the starting node and $A4$ is the ending one. Fig. 7 shows the results of this experiment as the comparison of amount of sent and reported traffic for each experiment execution.

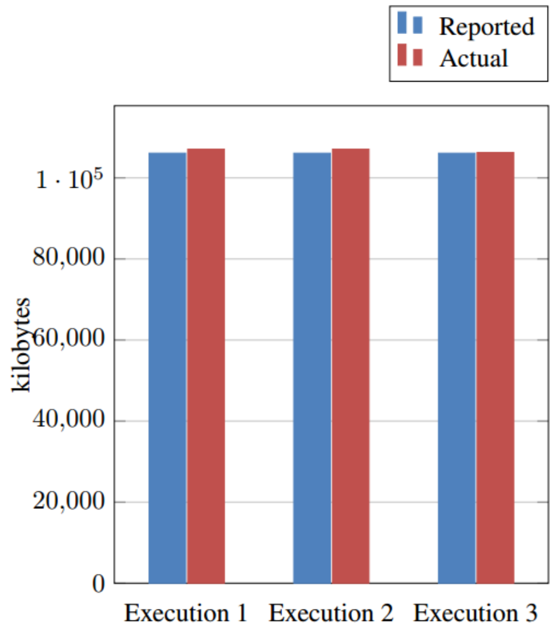

Fig. 7: Traffic reporting

7 Conclusions

In this paper we describe and experimentally validate the wireless mesh network resource management system based on an integration of the NUM-driven network control framework with the IMS architecture. We propose the specification and provide the first implementation of the CARMNET-XML protocol, which is used for communication between wireless nodes and IMS. In presented experiments, we evaluate the implementation in terms of the communication overhead, the waiting time needed to get the information on user profiles, and reliability of reporting features. The results confirmed the correctness of the implementation.

As a result of application of the IMS technology and a new light-weight CARMNET-XML protocol the solution may be used to build the carrier-grade system, which is unique due to its ability to provide the QoS functions for flows with different rate and delay requirements. The system may be additionally enhanced by providing the functions for exchanging the virtual utility units into the 'real' accounting units used by telecom operators.

Acknowledgement

This work is supported by a grant from Switzerland through the Swiss Contribution to the enlarged European Union (PSPB-146/2010, CARMNET), and by Poznan University of Technology under grant 45-105/13 DS-PB.

References

[1] Fokus Open IMS Core. http://www.openimscore.org/

[2] The Distributed Embedded Systems Testbed (DES-Testbed) Webpage. http://http://www.des-testbed.net/

[3] A. Achour, K. Haddadou, B. Kervella, and G. Pujolle. A SIP-SHIM6 Based Solution for Seamless Intra-Domain Mobility in IMS Networks. In *Proc. of Global Communications Conference (GLOBECOM)*, pp. 2030–2035, IEEE, 2012

[4] U. Akyol, M. Andrews, P. Gupta, J. D. Hobby, I. Saniee, and A. Stolyar. Joint scheduling and congestion control in mobile ad-hoc networks. In *Proc. of the 27th IEEE International Conference on Computer Communications (INFOCOM 2008)*, pp. 619 – 627, April 2008

[5] N. M. Alamri and N. Adra. Integrated MIP-SIP for IMS-based WiMAX-UMTS vertical handover. In *Proc. of the 19th International Conference on Telecommunications (ICT)*, pp. 1–6, April 2012

[6] N. Bayer, A. Roos, R.P. Karrer, B. Xu, and C. Esteve. Towards carrier grade wireless mesh networks for broadband access. In *Proc. of 1st Workshop on Operator-Assisted (Wireless Mesh) Community Networks* , pp. 1–10, 2006

[7] S.Y. Cheng and W.E. Chen. A Fast SA Update Mechanism for Secure SIP/IMS Mobility in Integrated UMTS-WLAN Networks. In *Complex, Intelligent, and Software Intensive Systems (CISIS)*, pp. 281–286, Taichung, Taiwan, 2013

[8] M. Glabowski and A. Szwabe. Carrier-Grade Internet Access Sharing in Wireless Mesh Networks: the Vision of the CARMNET Project. In *Proc. of the Ninth Advanced International Conference on Telecommunications*, June 2013

[9] M. Günes, F. Juraschek, B. Blywis, and O. Watteroth. DES-CRIPT - A Domain Specific Language for Network Experiment Descriptions, In *Proc. of the International Conference on Next Generation Wireless Systems (NGWS) 2009*, Melbourne, Australia, pp. 12-14, October 2009

[10] F. Kelly. Charging and rate control for elastic traffic. *European Transactions on Telecommunications*, 8(1):33–37, January 1997

[11] L. Le and G. Li. Cross-Layer Mobility Management based on Mobile IP and SIP in IMS. In *Proc. of 2007 International Conference on Wireless Communications, Networking and Mobile Computing*, pp. 803–806, September 2007

[12] A. Nowak, P. Walkowiak, A. Szwabe, and P. Misiorek. wnPUT Testbed Experimentation Framework. In L. Bononi, A. Datta, S. Devismes, and A. Misra, (Eds.), *Distributed Computing and Networking, Lecture Notes in Computer Science*, Vol. 7129, pp. 367–381, Springer Berlin Heidelberg, 2012

[13] C. Perkins. IP Mobility Support for IPv4, Revised. RFC 5944 (Proposed Standard), November 2010

[14] B. Radunovic, C. Gkantsidis, D. Gunawardena, and P. Key. Horizon: Balancing TCP over multiple paths in wireless mesh network. In *Proc. of the 14th ACM international conference on Mobile computing and networking, MobiCom 2008*, pp. 247–258, 2008

[15] A.B. Roach. SIP-Specific Event Notification. RFC 6665 (Proposed Standard), July 2012

[16] A. Szwabe. DANUMS: The First Delay-Aware Utility Maximization System for Wireless Net-

works. In *Proc. of NEM Summit - Towards Future Media Internet*, pp. 59–64, September 2009

[17] A. Szwabe, P. Misiorek, and P. Walkowiak. Delay-Aware NUM system for wireless multi-hop networks. In *Proc. of European Wireless 2011 (EW2011)*, pp. 530–537, Vienna, Austria, April 2011

[18] P. Walkowiak, R. Szalski, S. Vanini, and A. Walt. Integrating CARMNET system with public wireless networks. In *Proc. of ICN 2014, The Thirteenth International Conference on Networks*, 2014

[19] P. Walkowiak, M. Urbański, A. Figaj, and P. Misiorek. Integration of DANUM-based carrier-grade mesh networks and IMS infrastructure. In J. Cichon, M. Gebala, M. Klonowski (Eds.), *Ad-hoc, Mobile and Wireless Networks, ADHOC-NOW 2013, Lecture Notes in Computer Sciences*, Vol. 7960, pp. 185–196, Springer Berlin Heidelberg, 2013

[20] P. Walkowiak, M. Urbanski, M. Poszwa, and R. Szalski. Flow classification in Delay-Aware NUM-oriented wireless mesh networks. In *Proc. of MESH 2013, The Sixth International Conference on Advances in Mesh Networks*, pp. 33–38, 2013

[21] A. Warrier, S. Janakiraman, S. Ha, and I. Rhee. DiffQ: Practical differential backlog congestion control for wireless networks. In *Proc. of the 27th IEEE International Conference on Computer Communications (INFOCOM 2008)*, pp. 262 – 270, April 2009