Performance Evaluation of the CARMNET System in Metropolitan Wireless Networks

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***Abstract*—The paper presents the results on experimental CARMNET system deployment in metropolitan wireless networks. The system consists of several components among which the main role is played by CARMNET Loadable Linux Module. This module is aimed at providing the delay-aware resource allocation based on Delay-Aware Network Utility Maximisation System (DANUMS). The DANUMS-specific communication, including the reports on queue levels and delays, is realized by means of the Optimized Link State Routing (OLSR) protocol extension. By assuring theoretically-grounded high throughput effectiveness (based on max-weight scheduling) and carrier-grade network reliability, the solution provides the means for enhancement of the Internet access technology for commercial Internet Service Providers. At the same time, the system is aimed at supporting the development of purely-open, society-based, noncommercially-operated wireless networks that have recently gained popularity in several European agglomerations. In this paper, we describe the CARMNET application scenarios and results from first experimental deployment of the system in existing networks.**

Keywords-Wireless Mesh Networks; OLSR protocol, wireless network resource allocation, mobility

I. Introduction

Providing high-quality services for mobile devices is challenging task not only because of issues related to wireless communication 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. The CARMNET project [1], [2] addresses the above-mentioned task by providing the integrated solution involving resource management component based on Delay-Aware NUM (DANUM) System [3], an IMS infrastructure [4], multi-criteria routing component and the mobility component based on the WiOptiMo system [2]. The goal of the system is to make the user-provided Internet access a viable alternative to the currently widespread 3G/4G-based mobile Internet access, simultaneously providing the support for generalized network node mobility. The CARMNET resource management solution consists of two elements: the additional communication mechanism responsible for resource monitoring and reporting based on an extension of the OLSR protocol, and the scheduling component providing a delay-aware version of the Max-Weight Scheduling (MWS) 'backpressure' algorithm [5]. The extension of the OLSR protocol has been implemented as a plug-in of the OLSRd agent whereas the component providing application-layer approximation of the MWS policy has been deployed as a loadable Linux kernel module. The OLSR extension used in the CARMNET project has been specified in IETF Internet Draft [6], which describes signaling and processing that is necessary to be add to the standard OLSR communication in order to provide efficient traffic engineering supporting backpressure-based scheduling scheme [7]. The extension includes data flow identification, as well as periodical signaling of Queue Report (QR) and Urgency Report (UR) messages, which enable a router to monitor the queue levels of its neighbors.

In this paper, we focus on the issues of an efficient integration of the CARMNET system with the existing infrastructure of wireless local and metropolitan networks. The presented proof-of-concept integration activities include the experiments on the CARMNET system in the metropolitan networks Lugano Wifi [8] and Poznan INEA [9]. Additionally, the CARMNET system deployment issues are discussed from the perspective of testing the performance of CARMNET Loadable Linux kernel module (in the public free-to-use wireless network Malta NET [10] located at Poznan), and from the perspective of future tests in metropolitan public wireless networks which (similarly as in the case of CARMNET) apply the OLSR protocol including: Opennet Initiative [11] operating in Germany, and Ninux [12] operating in Italy.

II. Related Work

The resource management subsystem applied in the CARMNET system is based on underlying DANUM System (DANUMS) [3], which is an extension of Network Utility Maximisation (NUM) framework [5]. In contrast to standard NUM solutions, DANUMS aims to increase overall network utility by means of virtual queuing which model both throughput and delay influence for each flow utility [3]. While other NUM-based systems exist [13]–[15], only DANUMS is able to response for delay requirements of VoIP and other time-sensitive flows. Moreover, from the communication perspective, the solution is integrated with the OLSR protocol, which remains the leading routing protocol for wireless networking used by many existing wireless communities including [11], [12] as well as the Openwireless network [16] operating in Zurich (Switzerland) and wasabi.net [17] operating in St. Louis (USA).

The CARMNET system main objective is to provide the new abilities of Internet sharing, in particular related to extending of network coverage (by means of users' nodes serving as routers) and mobility support scenarios. Different approaches of Meraki and FON to the Internet sharing supported by community of user have been studied [18]. FON solution encourages users to share their Internet access by promising of receiving the same in return. The dedicated hardware is used for sharing, which operates as access-point with captive portal. Meraki is the example of a company which allows to create wireless networks controlled by centralised entity enabling easy accounting (according to the more and more popular software-defined networking architecture). This solution provides fine control of traffic, but mainly from the perspective of the network administrator who provides the network hardware. In contrast, the CARMNET solution aims to provide the opportunity to create networks built by both commercial entities and community driven initiatives. Users can contribute by both supplying alternative Internet-access gateways and extending range of the network using their own devices.

III. The Architecture of the CARMNET System

The CARMNET system has been presented in [2]. The system allows its users to share their resources in order to share Internet access. The CARMNET system goals include providing an access to the Internet in places without (or with very weak) WiFi signal from the static infrastructure. The system employs wireless nodes to extend the range of a network, therefore, it may be particularly useful in metropolitan networks, where extending range by means of a static infrastructure can be expensive. The system consists of multiple components deployed both on a client- and server-side. The CARMNET system architecture is illustrated in Figure 1 [2].

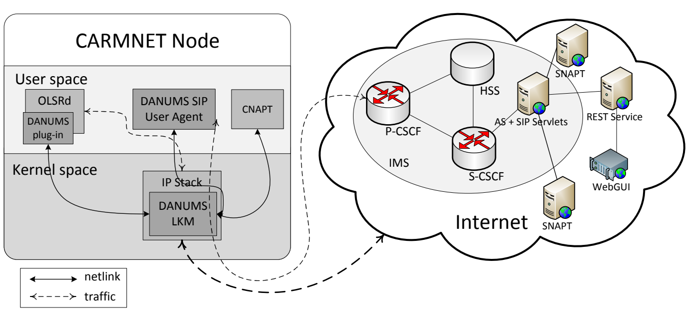

Figure 1: Architecture of the CARMNET system.

The CARMNET Linux Loadable Kernel Module (LLKM) [3] works in the kernel space, what allows for an integration with the network stack necessary to introduce new queuing and scheduling mechanisms. The OLSR daemon, a popular implementation of the OLSR routing protocol, is used for the network path resolution and signaling the DANUM-specific information in a distributed way. To ensure a communication between both subsystems, deployed in both the kernel and user space respectively, the Netlink protocol is applied. The Netlink protocol is used to communicate with the client-side part of the CARMNET mobility subsystem based on the WiOptiMo framework. The mobility services are provided by means of the client proxy - CNAPT - installed on the CARMNET wireless node. The role of this component is to intercept traffic flows associated to the mobility service and relay them to the SNAPT server. The last subsystem employed on a CARMNET Wireless node is a DANUMS SIP User Agent, which is responsible for exchanging information with an IMS architecture. This integration allows the CARMNET system to use an enhanced IMS infrastructure to provide the session and user management and exploit the unique features of an utility-aware flow control and resource allocation (provided by DANUMS [3]). As a result of integrating the carrier-grade AAA with the NUM-oriented resource management, the system enables the application of utility-based charging based on the virtual units of utility (*denarii*), which may be used as a market-like regulator for utility- and reliability-oriented resource allocation. More details about the CARMNET system architecture and implementation, including the issues concerning DANUM-related utility-based charging may be found in [2].

IV. Integration with Existing Networks

The presented experimental deployment results assumes the integration strategy in which we integrate the CARMNET system only to the network client software and reuse the own Authentication, Authorisation and Accounting (AAA) system of the network (if exists), at the same time. This approach is focused at the extension of range of an existing wireless network, which, as a result of integration with CARMNET, may cover the previously inaccessible areas, without the use of any additional static infrastructure. It is achieved by deploying additional software on clients' devices. This software is responsible for advanced resource management as well as for network access sharing. As mentioned above, the optimization of resource usage is done in a distributed way by each of the CARMNET-compatible network components. In this scenario, optimization is performed locally, between clients' nodes and not throughout the network. Access points are not modified.

For real-world scenarios, the integration strategy limited to client nodes is much easier to realize. Many already existing network infrastructures have well established AAA capabilities. Full integration with those would require additional implementation effort (including additional modification of the existing infrastructure software) making the solution less interesting for network operators. Moreover, we are currently not prepared to support any other platform than the Linux-based one.

V. Networks Used for CARMNET System Deployment Tests

This section describes networks chosen for performance evaluation of the CARMNET system. The experimentation results concerning two of them (i.e., Lugano WiFi and INEA), have been presented in the section describing experiments. More details concerning these networks may be found in [8], [9].

A. The Lugano WiFi Network

The Lugano WiFi network is available in different discontinuous areas of Lugano. For our experiments, we have decided

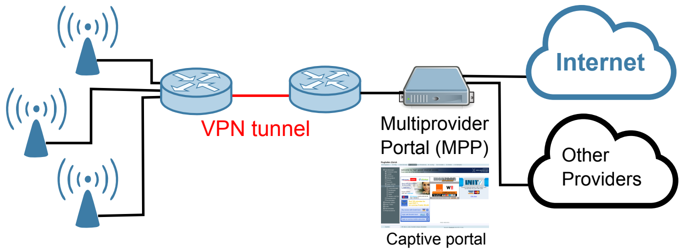

Figure 2: Lugano WiFi architecture.

to focus only on the city centre area which, due to the way it is covered, is more appropriate for the presented scenarios [8].

The network is managed by the WLAN-Partner company [19]. The solution currently used by Lugano WiFi to manage handovers is based on tunnelling (Figure 2). A Virtual Private Network (VPN) tunnel is opened between the core router and the WLAN-Partner data centre. A software called Multiprovider Portal (MPP) performs AAA functions. It is based on the Linux application for packet filtering *iptables* and consists of a combination of rules and rulesets. The average number of devices connected to the network is 1340 per month (about 45 per day), while the number of sessions per workday is 5050 and the average duration is about 25 minutes. The more details about MPP system may be found in [8]. During the experiments, a set of special accounts without session time limit were used, for practical reasons.

B. The INEA HOTSPOT Network

At the time of conducting tests, the INEA HOTSPOT network consisted of about 40 fixed and 400 mobile hotspots [9]. Those WiFi nodes provide Internet access to customers located in Poznan Metropolitan Area. The hardware platform selected for the project is based on MikroTik RouterBOARD devices [20]. Apart from being deployed in public places, INEA HOTSPOTs are also installed in means of the public transport, i.e., trams and buses. Such an approach allows INEA to cover the busiest areas of Poznan.

Figure 3 shows generalized logical topology of components that the INEA HOTSPOT network consists of. Users can use WiFi-enabled devices in order to connect to the network with SSID „INEA HotSpot". More details od INEA HOTSPOT network may be found in [9].

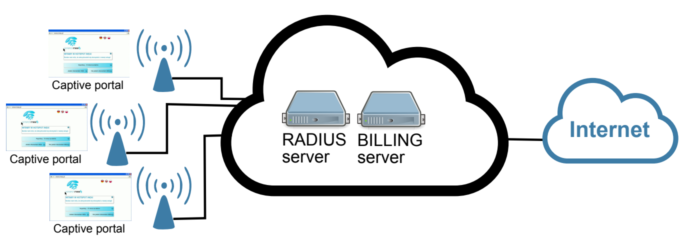

Figure 3: INEA HOTSPOT network architecture.

C. The Malta NET Network

A resource management subsystem developed in the CARMNET project, i.e., CARMNET Loadable Linux Kernel Module (CARMNET LLKM) has been experimentally used in public free-to-use wireless network Malta NET [10] located at Poznan. The main goal of this deployment effort is to obtain the feedback from the community-driven network users in developing new and testing existing features of the CARMNET system. As a result of opening the source code of the CARMNET solution to the community, a few improvements were introduced to the system (e.g., porting to the newer versions of Linux kernel). The deployment activities provided in the Malta NET network are focused on Linux-related performance issues of the CARMNET LLKM module operation.

VI. OLSR-Based Networks Planned for Additional Experimentation

In order to gather the results helpful for future CARMNET system optimization, we are going to conduct additional tests using existing metropolitan public networks which use OLSR protocol. In this section, the networks, which we contacted with, have been shortly introduced. Except the experimentation scenarios related to network coverage extension and seamless mobility, the planned tests will include the experiments aimed at optimization of OLSR-related mechanisms of CARMNET LLKM subsystem operation.

A. The Opennet Initiative Network

The Opennet Initiative [11] network is a part of the worldwide community-driven public networks called "Freifunk" [21]. All work in the network is done by volunteers, however, the network has strong relationships with local University of Rostock. The network is built on top of Ubiquity and TP-LINK consumer hardware with the support of the OpenWrt software. The access points are connected in a full mesh network using wireless, fibre and ethernet links with a dedicated VLANs in an shared metropolitan network as a backbone. Although the Opennet Initiative network is parted into multiple local mesh areas in different regions of the north Germany, all mesh networks are inter-connected through openvpn tunnels with routing based on the OLSR protocol. More details on Opennet Initiative including the network architecture and coverage area may be found in [11].

B. The Ninux Network

Ninux [12], [22] is a Wireless Community network located in Italy. The initiative started as a small-scale network in Rome with Internet access realized by NAT and shared user private connections. Currently, the Ninux network is distributed among Italy and driven by a community of geeks, fans and radio amateurs. The main goal of Ninux is to create an urban intranet for experimental purposes, regardless of the Internet connection. The network consists of many Access Points of different brands, however, most of them support the open source firmware OpenWrt based on the Linux kernel. Since the network is spread all over Italy (so it is impossible to provide the whole communication by means of wireless connection only), the Ninux network introduced a new routing architecture based on the OLSR and BATMAN routing protocols inside wireless mesh networks and BGP routing protocol between them. More details on the Ninux network may be found in [12], [22]–[24].

VII. Deployment Scenarios

In order to verify the effectiveness of integration, we define two scenarios. For each scenario, before conducting the experiments, each one has been performed locally in a wireless network testbed [25]. This testbed allows for an automated scenario execution using a set of ALIX integrated network nodes equipped with two network interfaces (a wired one for commands execution and a wireless one for experiment traffic). Those nodes are managed centrally using the wnPUT server capable of booting, restarting and issuing commands to groups as well as individual machines.

A. Network Coverage Extension

For the purpose of performing the network coverage extension experiment, the Carrier-grade delay-aware resource management for wireless multi-hop/mesh networks (CARMNET) network, consisting of at least 3 nodes, has to be set up. The experiment illustrates a practical usage scenario yielding immediate end-user gains that arise from the extension of Internet access availability. In the case of Lugano Wifi experimentation, a stationary node n_1 was connected to the network, during the whole experiment, and was acting as a final gateway for both n_2 and the $user$ node (see Figure 4). Node n_2 was connected to n_1 being, at the same time, outside the range of the public WiFi network. It had Internet access by means of Internet sharing from node n_1 only. The third node was simulating a user traveling along a linear path, from n_1, towards n_2 and beyond (see Figure 4). The user was initially connected to node n_1. While moving, as the signal strength of n_1 lowered, it changed the gateway to n_2. This was possible as a result of the Optimised Link State Routing Protocol (OLSR) daemon monitoring of the Expected Transmission Count (ETX) routing metric extension, determining changes in path quality. During movement, the user node was issuing Internet Control Message Protocol (ICMP) Echo Requests to an external address, reachable through the Internet, to check connectivity. At the end of the path, a Transmission Control Protocol (TCP) connection was established to download a 15 MB file using the *wget* application.

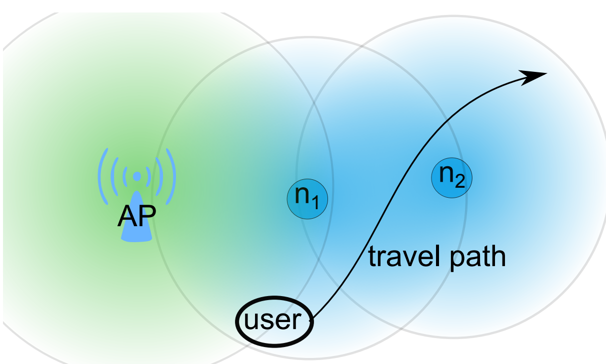

Figure 4: Network coverage extension scenario.

In the case of INEA HOTSPOT, the network coverage extension experiment has been carried out in the area of the Poznan University of Technology (PUT) campus, in which access to INEA HOTSPOT network has been possible – the network provided by operator was only visible to our devices in a small section of the PUT campus building. Our aim was to provide coverage of INEA HOTSPOT network inside the campus building, across all the floors. It has been performed with the use of our local wireless network testbed (the wnPUT testbed) [25]. We used a similar scenario as illustrated in Figure 4. Node n_1, acting as a gateway, was connected to the INEA HOTSPOT network and shared that Internet access with the rest of the mesh network. Remaining nodes were spread across the building and floors so that roughly the whole area of the building was covered with signal. Node $user$ (as a client) downloaded 100 MB of data using the TCP protocol to verify the connectivity. In contrast to the simplest case of single node extending the network coverage used in the experiment done in Lugano, (node n_2 in Figure 4), in the case of the experiment provided in the INEA HOTSPOT we apply two redundant paths to the operator network (see [9] for details).

B. Seamless Handover

The goal of the second scenario is to present the seamless handover functionality provided as a result of CARMNET system operation. In the case of Lugano Wifi, a CARMNET network, consisting of 3 nodes, has been set up to cover the signal gap between signal ranges of the network. Nodes were arranged in a linear topology, so that the first (n_1) and the last (n_2) node were connected to the Public WiFi network. The third CARMNET node was simulating a user traveling along the indicated path (see Figure 5). During its movement, it eventually move out of the Public WiFi's signal #1 range. Since the mobile node was a CARMNET node, once the signal #1 strength decreased under a certain threshold, Optimised Link State Routing Protocol daemon (OLSRd) automatically changed the routes and, as expected, the node was connected to the existing CARMNET network. A similar situation had taken place as the user node was leaving CARMNET network's range and approaching Public WiFi's signal #2 range.

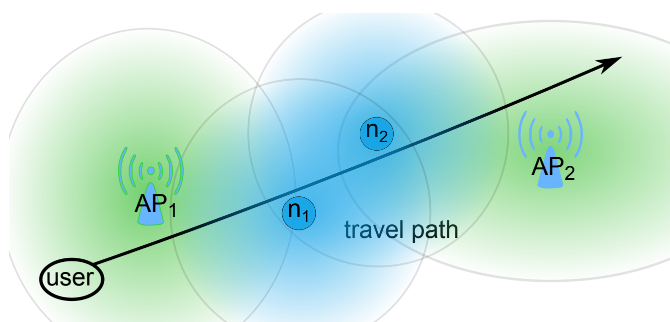

Figure 5: Handover experiment scenario.

In the case of handover experiment done in INEA HOTSPOT, we have connected two separate networks (the first one from INEA and the second one provided by PUT) by means of a CARMNET mesh network. As a result of the mobility subsystem [2] application, which is a part of the CARMNET system, users were able to switch networks seamlessly. In particular, two CARMNET nodes, n_1 and n_2, were acting as gateways. Node n_1 was connected to the INEA network and node n_2 was connected to the PUT network by means of an Ethernet cable. To validate the approach we have deployed a CARMNET user node (the client) that was moving from one network to another (see Figure 5) and was maintaining a TCP session. The user node was not able to be in range of both networks simultaneously and thus, it had to use the CARMNET mesh network, as means of preserving its sessions.

VIII. EXPERIMENTATION RESULTS

While testing the first scenario we have proved a successful extension of the Lugano WiFi network range, using the CARMNET nodes. Being connected to the CARMNET network, the user node was still able to access the Internet provided by Lugano WiFi, while being out of range of its infrastructure. Figure 6 shows the Denarii balance (see [2] for details on the CARMNET virtual charging system) over time for each node participating in the experiment, which illustrates how much each node shared/used the Internet connection. User node was initiating all the traffic what corresponds to a constant decrease of Denarii balance. Nodes n_2's virtual unit balance was oscillating around 0, since it was forwarding traffic. It is worth noting, that ultimately, node n_1 was sharing the Internet connection for the rest of the nodes and he was able to increase its Denarii balance. In the case of test provided in the INEA HOTSPOT, we transmit a TCP flow from from user node (the client) to a server located on the Internet. Measured throughput values fluctuate between 1.1Mbps and 2.8Mbps, because of wireless interference cause by other signals (see Figure 7). Overall mean throughput was 1.6Mbps. The link proved to be of enough good quality to sustain multiple user sessions. Additionally, the network topology has been confirmed by means of the `traceroute` command application. The results show that packets from the user node, targeting internet services, had to be routed by nodes of the CARMNET network first and through the INEA HOTSPOT network next.

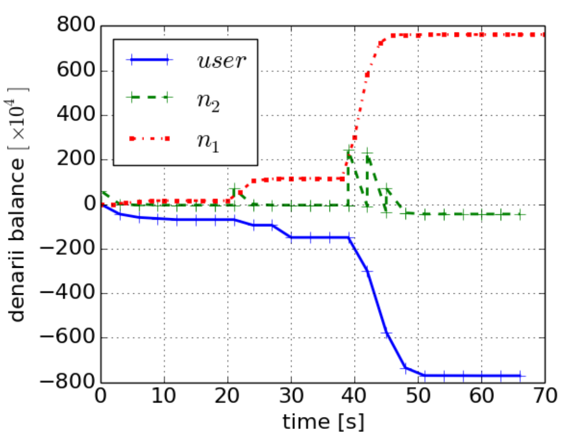

Figure 6: Denarii balance for the CARMNET nodes during the coverage extension experiment (Lugano WiFi).

Figure 8 shows a graph of TCP throughput for each of the CARMNET nodes participating in the seamless handover experiment (the case of test using the Lugano WiFi network). In the initial phase of the experiment, only node n_1 was in the range of the user node, so it was used as a default gateway and shared Internet access. As the user moved away from n_1, its Received Signal Strength (RSS) lowered and

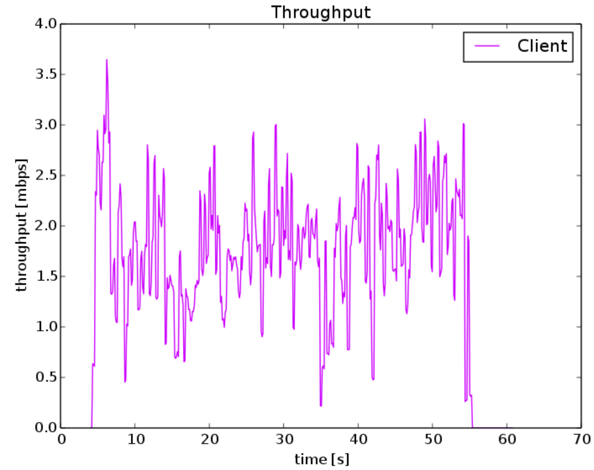

Figure 7: Flow throughput during the network coverage extension experiment (INEA HOTSPOT).

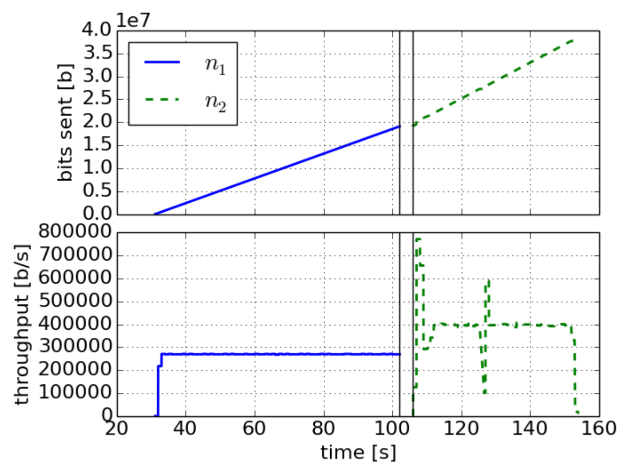

Figure 8: Throughput and total bits sent, registered at the 3 CARMNET nodes during the seamless handover experiment (integration with the Lugano WiFi networks).

the default route began to degrade (the value of ETX metric was rising). During this time, all of the traffic was sent through node n_1, what can be seen in Figure 8. Around the middle of the experiment, the user node detected the signal from the second gateway (n_2). Once the alternative route has got good enough ETX metric, the CARMNET mobility module based on WiOptiMo switched the routes and the flow was forwarded by the second node n_2. The brief increase in throughput, seen on the graph around 105th second, is caused by an accumulation of packets in the DANUMS queue after the handover has been completed. The overall 'goodput' of the flow, measured during the experiment, was 1.01 Mbit/s. It took 3.78 seconds to complete the handover. In the case of INEA HOTSPOT tests, a TCP transmission on the user node (the client) was started using the INEA Hotspot. Then, after 15 seconds, the node was moved out from the INEA Hotspot range into the range of PUT WiFi. Figure 9 presents results gathered during the experiment. The results confirmed seamless handover functionality – the transmission was continued by means of PUT WiFi Access Point after the change of the gateway. Due to the scenario-based characteristic

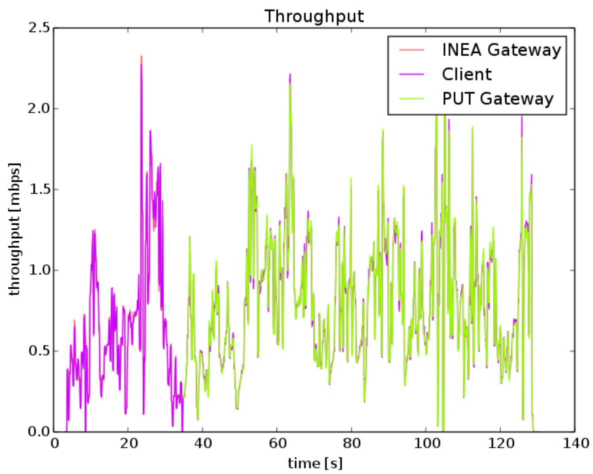

Figure 9: The throughput measured in the seamless handover experiment (integration with the INEA HOTSPOT network).

of presented experimentation, in all figures we have presented the results from a single execution of each test. However, we have repeated each experiment presented in the paper several times (5-10) obtaining similar and comparable results.

IX. Conclusion and Future Work

We have presented the results on experimental CARMNET system deployment in two metropolitan wireless networks. The goal of the presented deployment effort is to test the ability of the CARMNET system integration with the existing networks and to confirm the advantages of its operation in these networks. The presented experiments proved the CARMNET system ability to support the network coverage extension and seamless handover functions. As future work we are going to extend the experimentation on additional metropolitan networks [11], [12], which, similarly like the CARMNET resource management subsystem, use the OLSR protocol. OLSR-based networks, such as [10]–[12], [16], [17], are especially convenient for the CARMNET deployment purposes. Moreover, the extended experiments involving the use of the CARMNET utility-based charging subsystem are planned.

Acknowledgement

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