FLAVIA
FLexible Architecture for Virtualizable wireless future Internet Access

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Specific Targeted Research Project

FLAVIA
FLexible Architecture for Virtualizable wireless future Internet Access

D 8.3: Final Dissemination, Standardization, Exploitation, and LTE Applicability Report

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Other contributing partners	ALL
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Deliverable abstract	WP8 has two major goals: i) provide dissemination, standardization and exploitation for the ideas, solutions, and activities carried out in the project, and ii) assess the applicability of the FLAVIA vision and related solutions to 3GPP' specifications evolution. Deliverable D8.3 provides a detailed summary of the work performed by the partners towards achieving these goals during the project highlighting its major achievements.
Keywords	Dissemination, Standardization, Exploitation, LTE Applicability

***NOTE**: As the project did not end yet some relevant activities within WP8 might require an update of the document later. In particular, additional information might be updated in the following sections: project website statics, publications and other dissemination activities.*

Project co-funded by the European Commission within the Seventh Framework Programme		
DISSEMINATION LEVEL		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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Executive Summary

This report summarizes the details of the FLAVIA WP8 actions and results focusing on its two different tasks as defined by the project:

- Task 8.1: Dissemination, standardisation and exploitation
- Task 8.2: LTE applicability assessment

The document outline is structured in relation to the two tasks and a summary is provided next:

<u>Dissemination</u>

The dissemination activities during the project have focused on different aspects in order to cover a wide range of the potential audience interested in the research done in the FLAVIA project.

In the research side, 26 journal and 42 conference publications have been released to the research community summarizing the main findings of the project. The quality and quantity of the research output clearly exceeds the originally planned objectives.

With respect to reaching out for having an impact on related activities performed by different projects and research groups, 5 workshops, 3 panel discussions, 23 external presentations, one tutorial and one journal special issue have been organized. Moreover, a keynote speech in a wireless IEEE conference in USA was invited. These events allowed partners to interact with other researchers outside the FLAVIA project and several areas of collaboration were identified.

Finally, the wireless networks developer community was addressed by FLAVIA by publicly releasing an implementation of the Wireless MAC processor developed within the project. The implementation along with the corresponding documentation is posted in FLAVIA's website and a tutorial at the ACM SIGCOMM conference in 2012 was organized to increase its visibility.

<u>Standardisation</u>

In the standardization side the project contributions have impacted four main standardization bodies: 3GPP, ETSI, IEEE 802.11 and IEEE 802.16.

3GPP: The contributions to 3GPP focused in two major groups: System Architecture Working Group 1 (SA1) and Radio Access Network Working Group 2 (RAN2). In SA1 FLAVIA partners promoted the creation of a Study Item on RAN Sharing Enhancements and a new set of requirements enabling dynamic usage of RAN resources by multiple operators were defined. Based on this work a new Work Item has been created which will create normative text based on these requirements.
In the RAN2 side we did contributions to the Enhancements for Diverse Data Applications (eDDA) Work Item and after Rel'11 we focused on the newly established

Study Item “Small Cell Enhancements” contributing to the study of the impact of small-cell backhaul on the mobility performance within heterogeneous networks.

ETSI: The European Telecommunications Standards Institute (ETSI) launched an Industry Specification Group (ISG) on Autonomic network engineering for the self-managing Future Internet (AFI). FLAVIA contributed a use case entitled “Wi-Fi Network Robustness” based on a scenario of the same name presented in the FLAVIA D2.1.2 deliverable which covers several autonomic aspects. The input will be included in the ETSI AFI Technical Specification: Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet” (to be released in 2013).

IEEE 802.16: The contributions to IEEE 802.16 addressed different aspects subject of potential improvement. A remarkable impact was achieved by contributions to IEEE 802.16p (M2M) where FLAVIA’s proposals where incorporated into the final standard amendment.

IEEE 802.11: The contributions to IEEE 802.11 focused on enhancing IEEE 802.11s and IEEE 802.11aa and extending the flexibility of future standards by presenting technology developed in the project to the IEEE 802.11 Wireless Next Generation Standing Committee.

<u>LTE applicability assessment</u>
Task 8.2 progressed as scheduled and focused on the LTE applicability assessment of the WP2 architecture. Following the previous reviews of the main architectural building blocks and interfaces performed in deliverables D8.1 and D8.2, in this deliverable we completed the review by considering a last set of functions of FLAVIA’s architecture considered of major relevance. Specifically:

- Load Balancing
- Intercell Coordination
- Admission control
- Power Saving
- Paging

<u>Exploitation</u>
Based on the research done during the project several exploitation activities have been conducted by the partners in different areas. In the Intellectual Property Rights area, 4 patent applications have been filed to protect some of the main ideas developed. In the product development area, industry partners have transferred some of the technology developed to their business units: Small Cells (NEC), WiFi deployments (Telefonica), LTE/WiMAX usr terminal measurement framework (Sequans) and WiMAX/LTE base stations hardware platform (Alvarion).

1. Dissemination, Standardization and Exploitation Activities

1.1 Dissemination

Within Task 8.1 many dissemination activities have been conducted during the three years of the project. In the following we provide a detailed summary of the contributions performed based on the different dissemination channels used.

1.1.1 Summary of Dissemination Activities

The dissemination activities performed by the FLAVIA partners during the three years of the project are summarized in Figure 1. FLAVIA Dissemination Output. A very significant impact can be observed with the scientific publications and presentations side being especially remarkable. The large quantity of publications already accepted and the top venues that were addressed clearly demonstrate the quality of the research work performed.

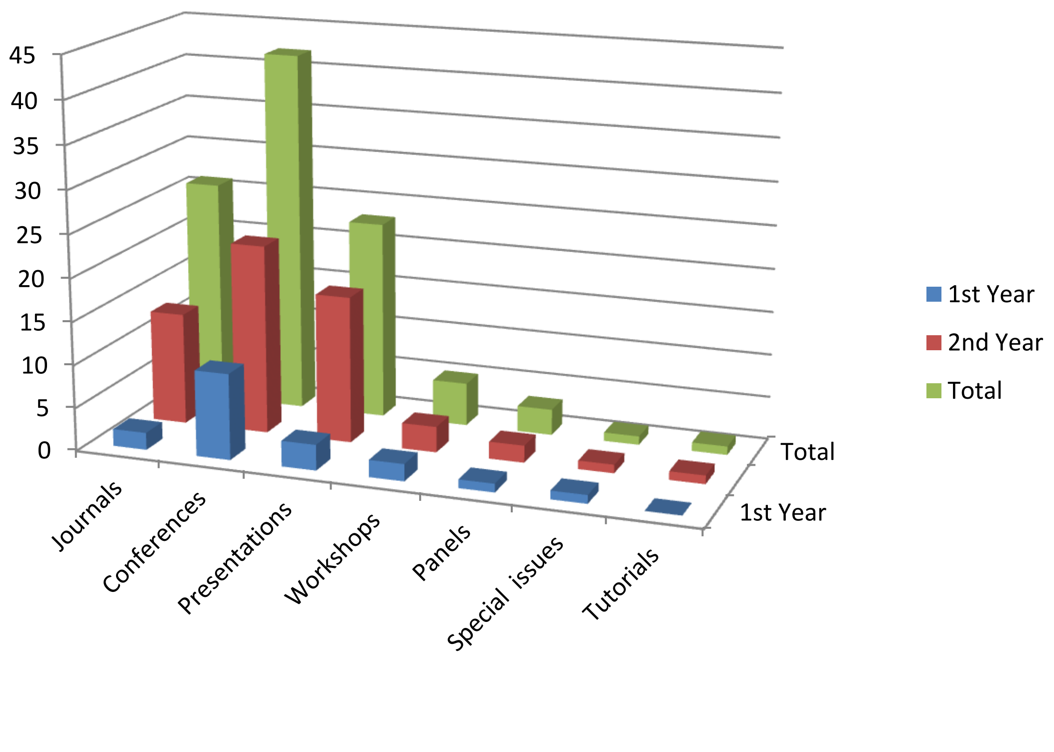


Figure 1. FLAVIA Dissemination Output

The information displayed in Figure 1. FLAVIA Dissemination Output is re-arranged in a different format in Figure 2. FLAVIA Dissemination Output Distribution depicting FLAVIA's dissemination output distribution. Especially remarkable in this case is the journal to conference ratio (above 50%) indicating the significant depth of the work performed.

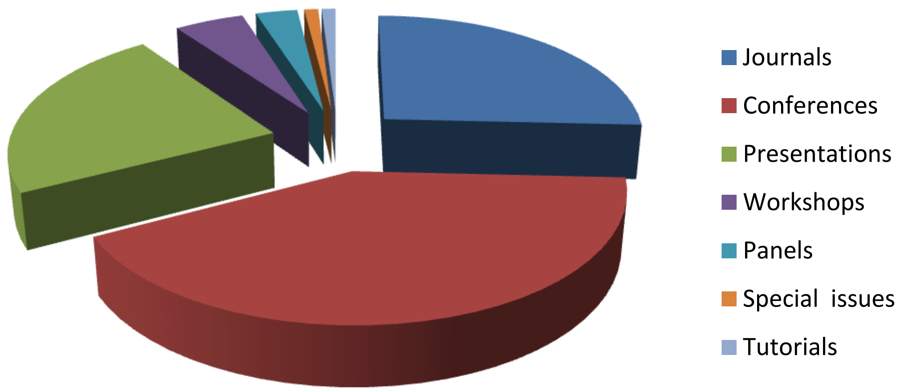


Figure 2. FLAVIA Dissemination Output Distribution

Considering the information provided in the previous two figures it can be concluded that FLAVIA had a remarkable impact in the research community exceedingly meeting its dissemination objectives. A detailed list of the dissemination output is provided in Section 3 and a selection next.

1.1.2 Dissemination Highlights

Given the large volume of the dissemination output of the FLAVIA project we provide here a few selected examples to help readers finding some highlighted work.

Wireless MAC Processor Public Release

FLAVIA has publicly released a Wireless MAC Processor implementation on a specific commercial wireless card. Documentation describing the API available on this platform (i.e. the list of events, actions and conditions to be used for defining MAC programs) and some tools for developing and debugging MAC state machines have been provided. Specifically, the tools include:

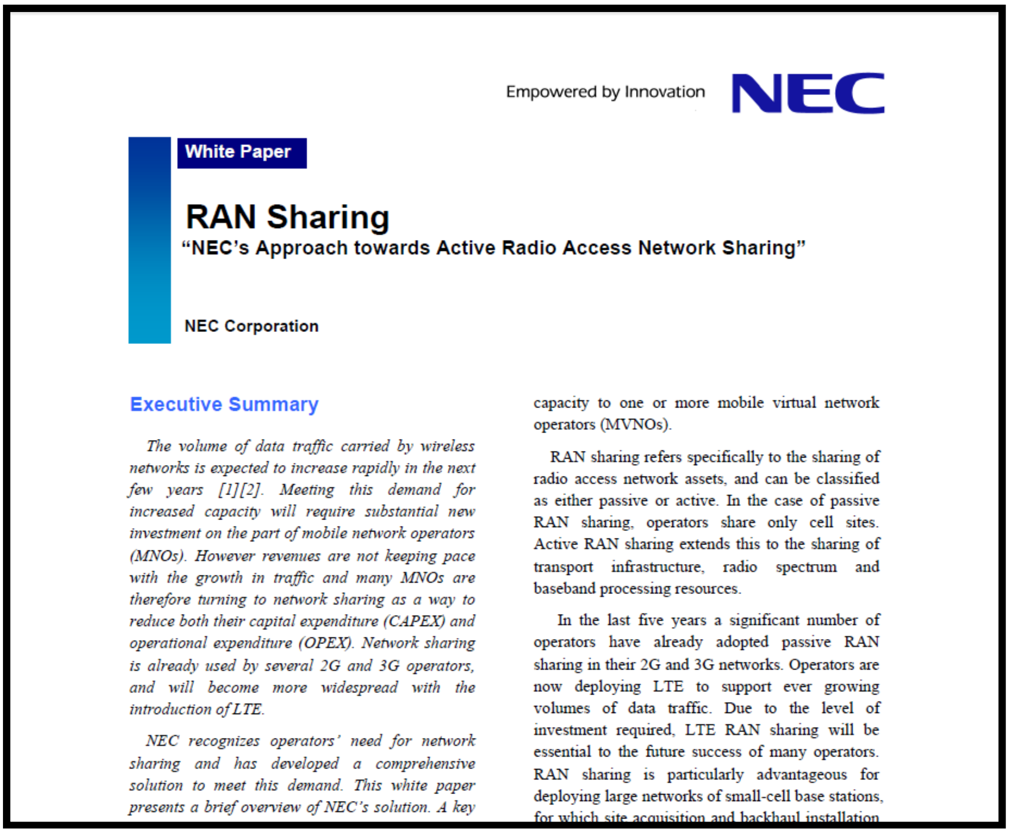
- A graphical tool, working as an editor for describing a MAC program in terms of a graphical representation of state transitions and state labels;
- A compiling tool, able to map the graphical representation into a textual transition table and in a ByteCode (i.e. a coded representation of the table to be loaded on the card);

- A ByteCode manager, able to read a ByteCode from the card and/or to inject the code in the WMP;

The combination of the MAC Engine, graphical editor, compiler, bytecode manager and driver is a complete and cheap tool-chain that allows developing and testing a new MAC scheme in a very simple, robust and quick way over an ultra-cheap platform. Each component of the tool-chain can be found on FLAVIA's website http://www.ict-flavia.eu and on the www.wmp.tti.unipa.it webpage (also realized by CNIT, thanks to contribution of the University of Palermo). More details on the WMP exploitation can be found in the Annexes I of the current document (see 4.1).

MWC 2013 - NEC's RAN Sharing White Paper

NEC released a white paper during the Mobile World Congress in 2013 summarizing "NEC's Approach towards Active Radio Access Network Sharing". NEC FLAVIA members actively contributed to the preparation of this white paper which describes some of the functionality developed by the company in its LTE products supporting some of the use cases for scheduled systems developed within the project. In the following figure a snapshot of the white paper is provided. The document can be found in: http://www.nec.com/en/global/solutions/nsp/lte_sc/doc/wp2013-3.pdf.


Empowered by Innovation NEC

White Paper

RAN Sharing

"NEC's Approach towards Active Radio Access Network Sharing"

NEC Corporation

Executive Summary

The volume of data traffic carried by wireless networks is expected to increase rapidly in the next few years [1][2]. Meeting this demand for increased capacity will require substantial new investment on the part of mobile network operators (MNOs). However revenues are not keeping pace with the growth in traffic and many MNOs are therefore turning to network sharing as a way to reduce both their capital expenditure (CAPEX) and operational expenditure (OPEX). Network sharing is already used by several 2G and 3G operators, and will become more widespread with the introduction of LTE.

NEC recognizes operators' need for network sharing and has developed a comprehensive solution to meet this demand. This white paper presents a brief overview of NEC's solution. A key

capacity to one or more mobile virtual network operators (MVNOs).

RAN sharing refers specifically to the sharing of radio access network assets, and can be classified as either passive or active. In the case of passive RAN sharing, operators share only cell sites. Active RAN sharing extends this to the sharing of transport infrastructure, radio spectrum and baseband processing resources.

In the last five years a significant number of operators have already adopted passive RAN sharing in their 2G and 3G networks. Operators are now deploying LTE to support ever growing volumes of data traffic. Due to the level of investment required, LTE RAN sharing will be essential to the future success of many operators. RAN sharing is particularly advantageous for deploying large networks of small-cell base stations, for which site acquisition and backhaul installation

Figure 3 "NEC's Approach towards Active RAN Sharing", White Paper

Journal Publications

- 'Radio Access Network Virtualization for Future Mobile Carrier Networks', IEEE Communications Magazine, Special Issue on Future Carrier Networks, June, 2013.

✓ Abstract: This article presents a survey of cellular network sharing which is a key building block for virtualizing future mobile carrier networks in order to i) address the explosive capacity demand of mobile traffic, and ii) reduce the CAPEX and OPEX burden faced by operators to handle this demand. We start by reviewing the 3GPP network sharing standardized functionality followed by a discussion on emerging business models calling for additional features. Then, an overview of the RAN Sharing Enhancements currently being considered at the 3GPP RSE Study Item is presented. Based on the developing network sharing needs, a summary of the state of the art of mobile carrier networks virtualization is provided, encompassing RAN sharing as well as a higher level of base station programmability and customization for the sharing entities. As an example of RAN virtualization techniques feasibility, a solution based on spectrum sharing is presented: Network Virtualization Substrate (NVS) which can be natively implemented in base stations. NVS performance is evaluated in an LTE network by means of simulation showing that it can meet the needs of future virtualized mobile carrier networks in terms of isolation, utilization and customization.

- 'A Game Theoretic Approach to Distributed Opportunistic Scheduling', IEEE/ACM Transactions on Networking, December 2012.

✓ Abstract: Distributed opportunistic scheduling (DOS) is inherently more difficult than conventional opportunistic scheduling due to the absence of a central entity that knows the channel state of all stations. With DOS, stations use random access to contend for the channel and, upon winning a contention, they measure the channel conditions. After measuring the channel conditions, a station only transmits if the channel quality is good; otherwise, it gives up the transmission opportunity. The distributed nature of DOS makes it vulnerable to selfish users: By deviating from the protocol and using more transmission opportunities, a selfish user can gain a greater share of wireless resources at the expense of "well-behaved" users. In this paper, we address the problem of selfishness in DOS from a game-theoretic standpoint. We propose an algorithm that satisfies the following properties: 1) When all stations implement the algorithm, the wireless network is driven to the optimal point of operation; and 2) one or more selfish stations cannot obtain any gain by deviating from the algorithm. The key idea of the algorithm is to react to a selfish station by using a more aggressive configuration that (indirectly) punishes this station. We build on multivariable control theory to design a mechanism for punishment that is sufficiently severe to prevent selfish behavior, yet not so severe as to render the system unstable. We conduct a game-theoretic analysis based on repeated games to show the algorithm's effectiveness against selfish stations. These results are confirmed by extensive simulations.

Conference Publications

- 'MAClets: Active MAC Protocols over Hard-Coded Devices', ACM CoNEXT, December 2012.

✓ Abstract: We introduce MAClets, software programs uploaded and executed on-demand over wireless cards, and devised to change the card's real-time medium access control operation. MAClets permit seamless reconfiguration of the MAC stack, so as to adapt it to mutated context and spectrum conditions and perform tailored performance optimizations hardly accountable by an once-for-all protocol stack design. Following traditional active networking principles, MAClets can be directly conveyed within data packets and executed on hard-coded devices acting as virtual MAC machines. Indeed, rather than executing a pre-defined protocol, we envision a new architecture for wireless cards based on a protocol interpreter (enabling code portability) and a powerful API. Experiments involving the distribution of MAClets within data packets, and their execution over commodity WLAN cards, show the flexibility and viability of the proposed concept.

- 'Mobile Access of Wide-Spectrum Networks: Design, Deployment and Experimental Evaluation', IEEE INFOCOM, April 2013.

✓ Abstract: Wireless networks increasingly utilize diverse spectral bands that exhibit vast differences in both transmission range and usage. In this work, we present MAWS (Mobile Access

✓ of Wide-Spectrum Networks), the first scheme designed for mobile clients to evaluate and select both APs and spectral bands in wide-spectrum networks. Because of the potentially vast number of spectrum and AP options, scanning may be prohibitive. Consequently, our key technique is for clients to infer channel quality and spectral usage for their current location and bands using limited measurements collected in other bands and at other locations. We experimentally evaluate MAWS via a widespectrum network that we deploy, a testbed providing access to four bands at 700 MHz, 900 MHz, 2.4 GHz and 5 GHz. To the best of our knowledge, the spectrum of these bands is the widest to be spanned to date by a single operational access network. A key finding of our evaluation is that under a diverse set of operating conditions, mobile clients can accurately predict their performance without a direct measurement at their current location and spectral bands..

Keynote speech

- Wireless MAC layer Reconfigurability from an SDN perspective - this keynote speech, held in Banff, Canada, on March 2013, provides a very broad and strategic (retrospective) view of the work carried out in FLAVIA in terms of wireless MAC programmability. The goal of this talk is to show that FLAVIA work is not only perfectly aligned to the current work on software-defined networking in the wireless domain, but it is actually pioneering new data plane abstractions which can be exploited by emerging software-defined networking paradigms.

Workshop Organization

'International Workshop on Wireless Access Flexibility (WiFlex)', September 2013, Kaliningrad, Russia

FLAVIA organized the 'WiFlex' workshop in Russia in 2013 on the topic 'Wireless Access Flexibility'. The aim of the workshop was to discuss the flexibility level of the architecture needed for the next generation wireless communications. The workshop will feature keynote presentations by Professors Adam Wolisz, Petri Mähönen and Mischa Dohler.

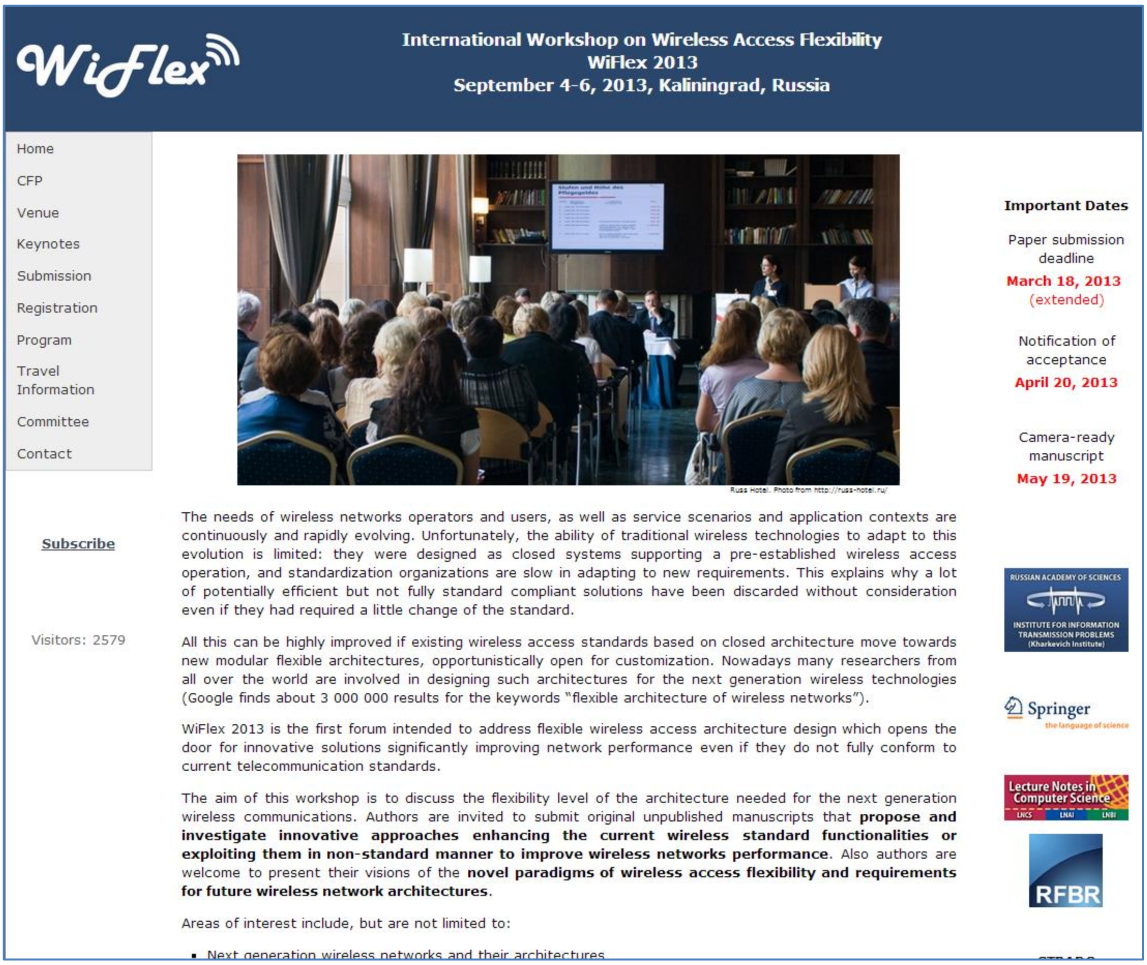


Figure 4. International Workshop on Wireless Access Flexibility (WiFlex), 2013

Demo at INFOCOM 2013

'Deploying Virtual MAC Protocols Over a Shared Access Infrastructure Using Maclets'

FLAVIA demonstrated the Maclets concept at the INFOCOM conference in April 2013.

Figure 5. Demo at INFOCOM 2013

1.1.3 Project Website

The new project website has been launched in June 2012 and follows the 2-3 column layout grid (most well-liked layout in the internet). The structure of this layout allows an easy expansion of the overall text (from 2 to 4 columns depending on the content posted) in order to populate the website according to the project evolving needs. The website layout has been improved to provide an easier and more appealing access to the project content and main results and a number of updates have been realised. This activity has been considered very important in order to support the dissemination and exploitation activities during the final phases of the project.

Figure 6: Snapshot of FLAVIA's new website

FLAVIA Website Statistics

FLAVIA's project website has been subscribed to the "Google analytics" service in order to evaluate the overall number of access from the users. The subscription to the service has been realised in September 2011. The figures realised during the period (September 2011 – June 2012) have been of overall more than 700 visits in 10 months. During the considered period visits have been almost 1500, with 3,667 pageviews.

In the following pages, figures based on Google Analytics in regard to the Visitors Flow and language, and Audience overview are reported for the period September 2012-May 2013. The websites has registered an average of 10-17 visits per day, mainly coming from users using the USA language (46,26%): this is indeed might be due to the impressive dissemination and exploitation activities that have been extensively made by all the project partners outside EU.

Secondly, 7.2% of the contacts have been made from Italian based users (which is actually due to the visits made by CNIT teamwork to update the website), and following by the other EU countries (see figure 7 below). It can be noted also that the percentage of new visitors in comparison to the returning ones is of 65.2% to 34.8%: this might be an indicator of good dissemination made by the project during events and conference, and can be a good outcome of the regular updates on news and deliverable releases.

Google Analytics

Go to this report

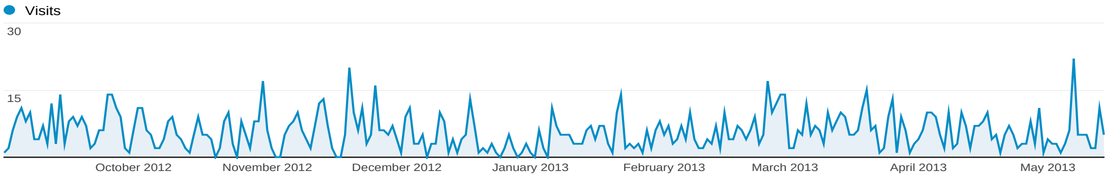
http://www.ict-flavia.eu - http://www.ict-flavia.eu
www.ict-flavia.eu [DEFAULT]

Audience Overview

1 Sep 2012 - 14 May 2013

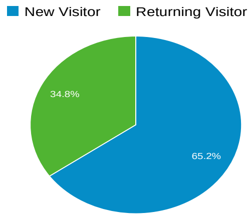
% of visits: 100.00%

Overview



982 people visited this site

Visits	1,457
Unique Visitors	982
Pageviews	3,667
Pages / Visit	2.52
Avg. Visit Duration	00:01:54
Bounce Rate	54.50%
% New Visits	65.20%



	Language	Visits	% Visits
1.	en-us	674	46.26%
2.	it	111	7.62%
3.	it-it	104	7.14%
4.	zh-cn	52	3.57%
5.	pt-br	47	3.23%
6.	pl	46	3.16%
7.	en-gb	42	2.88%
8.	es	42	2.88%
9.	fr	38	2.61%
10.	de-de	37	2.54%

view full report

Figure 7: Google analytics statistics for FLAVIA's project website (Audience overview)

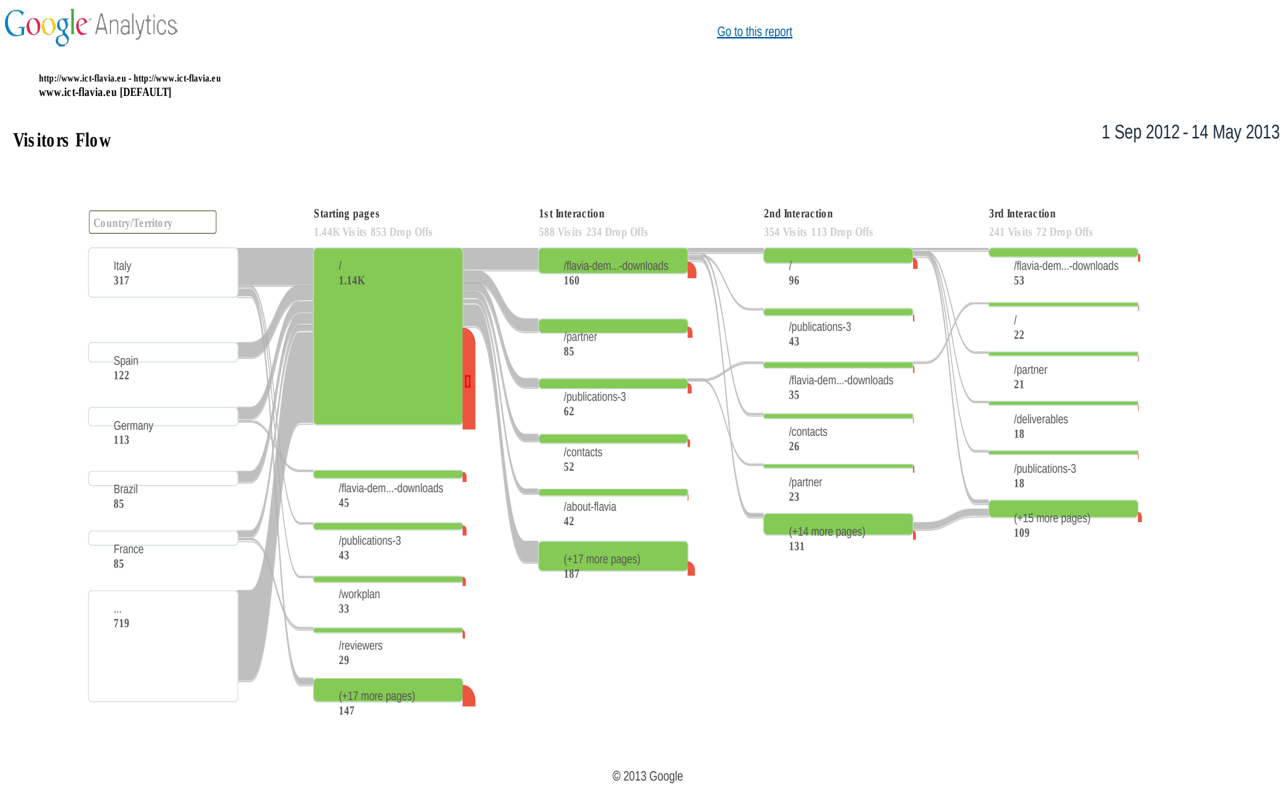


Figure 8: Google analytics statistics for FLAVIA's project website (Visitors flow)

The outline of the visitor's flow, clearly underlines the interest that the audience have had in regard to the demo/downloads, which actually has registered the highest number of visits (after the ones made to the main page). Specifically in the demo/download section the development of an open source release of the Wireless MAC processor were provided. In particular the following components can be downoadedl from the website:

- the WMP manual, describing the card models supporting our current implementations
- the WMP Editor (graphical tool), for programming a new MAC protocol in terms of state machine;
- the WMP bytecode manager, for compiling the graphical state machines in a readable machine code;
- the WMP firmware (closed source, but source code is available upon request) to substitue to the original 802.11 firmware;
- some MAC examples, both in terms of graphical and bytecode representations.

1.2 Standardization

1.2.1 3GPP

3GPP SA1 Activities – RAN Sharing Enhancements

3GPP has recognized the importance of supporting network sharing since Release 6 and defined a set of architectural requirements [3GPP-NS] and technical specifications [3GPP-NS-Arch] which have been updated at the time of writing this article until Release 10 and 11, respectively.

The standardized network sharing functionality has been enough to cover operators' requirements in the past. However, as operators look for new ways to reduce costs due to their increasing financial investment burden, new business models for operators and infrastructure owners are emerging, calling for an extension to existing standardized network sharing functionality.

The 3GPP RAN Sharing Enhancements (RSE) Study Item [3GPP-RSE] of the System Architecture Working Group 1 (SA1) has defined new scenarios of multiple operators sharing radio network resources. FLAVIA partners have actively contributed to this effort and were appointed as the official 3GPP RSE Study Item Rapporteurs. The objective of the RSE Study Item was to create requirements that complement existing 3GPP system capabilities for sharing common RAN resources.

The new scenarios aimed at:

- Provide means to be able to verify that the shared network elements provide allocated RAN resources according to the sharing agreements and/or policies.
- Provide means to act upon overload situations considering sharing agreements and/or policies.
- Provide means for efficiently sharing common RAN resources according to identified RAN sharing scenarios (e.g. pooling of unallocated radio resources).
- Provide means to flexibly and dynamically allocate RAN resources on-demand at smaller timescales than the ones supported today.

Based on these objectives several use cases were used to define future 3GPP requirements for RAN Sharing Enhancements.

RSE Monitoring: This use case describes the situation of a Hosting RAN Provider (primary RAN operator) that allows Participating Operators (e.g., MVNOs) to use a share of the RAN capacity where the amount of resources might be different for each participating operator. In such a scenario the hosting RAN shall allow participating operators to retrieve operation, administration and management (OAM) status information to the same level of detail as in a non-shared RAN for the share of their resources.

RSE Dynamic Capacity: This use case describes the situation of participating operators requiring varying network capacities during different time periods (e.g. within a day or week). Participating operators might request various allocations of a portion of the shared RAN in order to meet the projected variation in network usage requirements. An example for this use case could be an MVNO requiring significant RAN capacity during business hours but a lower capacity during the night or weekends.

RSE On-Demand Automated Capacity Brokering: This use case describes the situation of a hosting RAN provider that supports on-demand automated capacity requests from participating operators. A typical situation for this use case would be a hosting RAN provider with excess capacity during the night that participating operators could request on-demand, e.g., M2M services such as smart meter measurements. Another example could be a major event (e.g., sports, concerts, trade fairs, etc.) requiring additional capacity from a participating operator for that event. On-demand requests for capacity shall indicate the time period where the capacity is needed, the amount of capacity required and the specific service(s) treatment desired, e.g., based on standardized QoS Class Identifiers (QCIs). The hosting RAN provider then verifies automatically whether the RAN sharing request can be fulfilled and, in that case, the shared RAN is re-configured accordingly

RSE Load Balancing: This use case describes the situation of overlapping cells in a shared RAN. The hosting RAN shall be able to support load balancing within a shared RAN while respecting the agreed shares of RAN resources based on the whole cell load level and the load level for each participating operator. If the load levels of individual cells are exceeded the hosting RAN provider shall enforce agreed maximal usage limits of each participating operator by handing over UEs to neighboring cells.

This activity has raised a high level attention by many 3GPP stakeholders actively participating in the definition of the requirements. Based on the described use cases and additional ones that can be found in [3GPP-RSE] a set of new consolidated requirements has been derived. In the following table we summarize some of these main new requirements which illustrate the new functionality expected to be specified based on the RAN Sharing Enhancements Study Item contributions.

Hosting RAN Resources Allocation
• A Hosting RAN Provider shall be able to allocate the share of RAN capacity per Participating Operator as: – Fixed, minimum allocation guaranteed – Fixed for a period of time and/or sectors – First come-first served, i.e. on demand • A shared RAN shall be capable of providing differentiated traffic treatment per Participating Operator • A shared RAN shall conduct admission control based on the proportion of assigned RAN usage per Participating Operator
On-demand Capacity Negotiation
• The Hosting RAN shall be able to offer by automatic means shareable RAN resources as on-demand capacity to Participating Operators • Participating Operators shall be able to automatically request Hosting RAN offered on-demand resources • The Hosting RAN Provider shall allow a Participating Operator to request the cancellation of granted on demand requests • The Hosting RAN Provider shall be able to withdraw a granted request (within SLA limits)
OAM Access to the Hosting RAN
• The Hosting RAN shall be able to provide and control selective OAM access to Participating Operators • The Hosting RAN shall be able to allow Participating Operators to retrieve selective OAM status information to the same level of detail as would be available from a non-shared RAN
Handovers due to RAN Sharing Agreements
• Participating Operators shall be able to direct UEs towards the Hosting RAN at the beginning of a RAN Sharing period • A Hosting RAN Provider shall be able to direct UEs away from the Hosting RAN at the end of a RAN Sharing Period • Participating Operators shall be involved in the handover decisions at the end of a RAN Sharing Period

Table 1. 3GPP SA1 RAN SHARING ENHANCEMENTS STUDY ITEM, CONSOLIDATED REQUIREMENTS SAMPLE, TR 22.852

These set of new requirements illustrate the paradigm change being defined by the RSE Study Item work. The 3GPP acceptance of automated means (no human intervention) to allocate RAN resources dynamically and on-demand deserves special mention. This enhanced functionality opens the door to new industry players as well as to an evolution of operators' business models which could have a deep impact on the industry. Additionally, the enhanced sharing flexibility along the capacity, time and sector dimensions enable for a higher efficiency of RAN infrastructure exploitation.

See [RSE-IEEE Com Mag] to obtain further details about the RSE study Item and a description of ongoing implementation solutions.

At the time of writing this document the RAN Sharing Enhancements Study Item work in the technical report TR 22.852 has been completed and a new Work Item created to produce the corresponding normative text [3GPP-RSE-WI].

3GPP RAN2 Activities

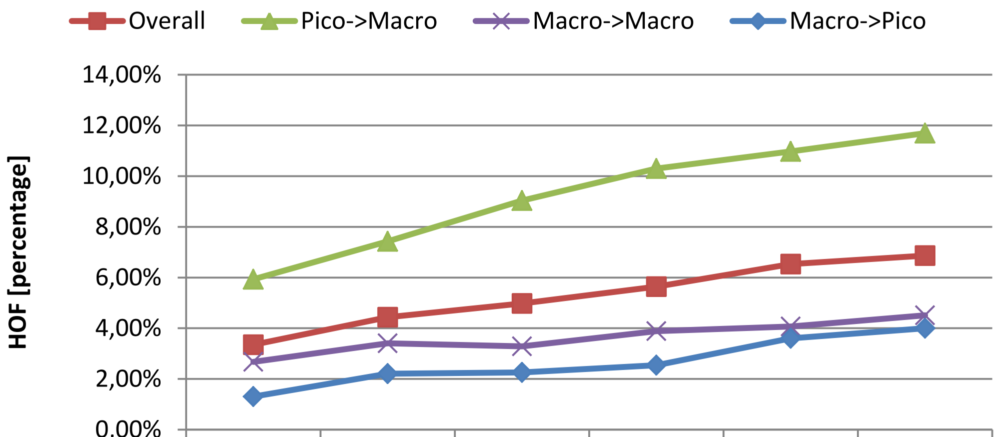
After the completion of Rel-11, FLAVIA's activities within 3GPP RAN2 focus on the newly established Study Item "Small Cell Enhancements – Higher Layer Aspects" [RP-122033]. This study item focuses on four topics:

- Feasible scenarios and benefits of UEs having dual connectivity to macro and small cell layers,
- Architecture and protocol enhancements for dual connectivity,
- Mobility mechanisms for minimising inter-node UE context transfer and signalling to the CN,
- Measurement and cell identification enhancements (for new use cases which were not discussed in the HetNet SI).

So far, FLAVIA contributed to the standardization process with two contributions, i.e.

- R2-130487, Impact of small-cell backhaul parameters on handover performance,
- R2-131309, Small Cell Enhancements for UL/DL Power Imbalance in Dual Connectivity Scenarios.

The former contribution is based on a system level simulator which has been developed within the FLAVIA project and allowed for a rapid implementation of new scenarios due to its modularity. In this contribution, we considered the impact of small-cell backhaul on the mobility performance within heterogeneous networks. It has been pointed out in [RP-122033] that small-cells may be connected via ideal and non-ideal backhaul, which may has an impact on the assumptions as derived in [TR 36.839] and inherently on the handover performance results.



	25ms	50ms	75ms	100ms	125ms	150ms
Overall	3,35%	4,43%	4,98%	5,64%	6,53%	6,87%
Pico->Macro	5,93%	7,43%	9,04%	10,30%	10,97%	11,69%
Macro->Macro	2,68%	3,41%	3,28%	3,89%	4,07%	4,51%
Macro->Pico	1,30%	2,21%	2,25%	2,54%	3,60%	4,00%

HO preparation time

Figure 9 Impact of backhaul delay on handover performance

The figure above shows the simulation results which illustrate the dependence of the handover performance on the handover preparation time. The handover preparation time directly depends upon the backhaul delay. In 3GPP RAN, different types of ideal and non-ideal backhaul are considered with delays of up to 60ms. The simulation results show very well that within the considered parameter range, the handover failure rate doubles which implies that the high delay needs to be taken into account during the handover process.

In our contribution R2-131309, we discussed potential issues that may arise in the case of dual connectivity. Dual connectivity refers to the ability of the user terminal to connect to a macro eNB and pico eNB at the same time. This may facilitate new concepts such as having only UL or DL data plane to one eNB or to support inter-eNB carrier aggregation. This makes it an attractive use case for FLAVIA as the modular concept of FLAVIA allows for implementing new concepts without implying significant changes. Furthermore, FLAVIA defines abstract interfaces between the individual modules and does not define where those interfaces are executed (or whether both modules need to be placed on the same entity). Therefore, the FLAVA framework already provides the software tools to implement the ne concepts developed within the context of dual connectivity.

Further topics that are monitored within 3GPP LTE RAN2 are:

Study Item WLAN/3GPP Radio Interworking

So far, 3GPP and WLAN are only integrated on core network level but on radio access network level. With the increasing density of WLAN access points that are controlled by operators, also the need increases to integrate WLAN and 3GPP on radio access in order to improve user experience, improve operator control, enable higher network utilization, and to reduce OPEX.

Within this 3GPP RAN study item, scenarios are identified where a tighter integration of 3GPP and WLAN may be considered. Particular attention is paid for mobility between 3GPP and WLAN. The three main issues that are covered are under-utilized operator-controlled WLAN networks, suboptimal user experience if a terminal connects to an over-utilized WLAN network, and unnecessary WLAN scanning which eventually cause a rapid decrease of battery energy.

This study item is of interest for FLAVIA, as FLAVIA already allows for a tight software integration of 3GPP LTE and WLAN due to its modular concept.

Work Item HetNet Mobility

This work item is a continuation of the study item which finished with Rel-11. For further information on the study item please refer to D8.2. Based on the findings during the study item phase, RAN explores during work item phase methods to improve the overall handover performance, to improve the small-cell discovery/identification with respect to battery utilization but without significant implications on the small cell offloading potential, to improve the mobility robustness, and to improve handover performance during long DRX.

1.2.2 ETSI

Network autonomicity is a research concept that is being widely investigated by research centres, industry, and standardization bodies. It allows lowering the overall network operating expenditure which is a key requirement for network operators. To address the problem of autonomicity, the European Telecommunications Standards Institute (ETSI) launched an Industry Specification Group (ISG) on Autonomic network engineering for the self-managing Future Internet (AFI). This group is playing a leading role in the (pre-)standardization process and AGH is actively involved in their work.

One of the first achievements of the ETSI AFI ISG is the definition of an architectural reference model for autonomic networking [Wodczak2011]. This reference model is based on the GANA Reference Model [Chaparadza2008], [Chaparadza2009]. To summarize, the reference model consists of Decision Elements (DEs) which govern Managed Entities (MEs) through control loops (). These DEs are organized in a hierarchical manner ().

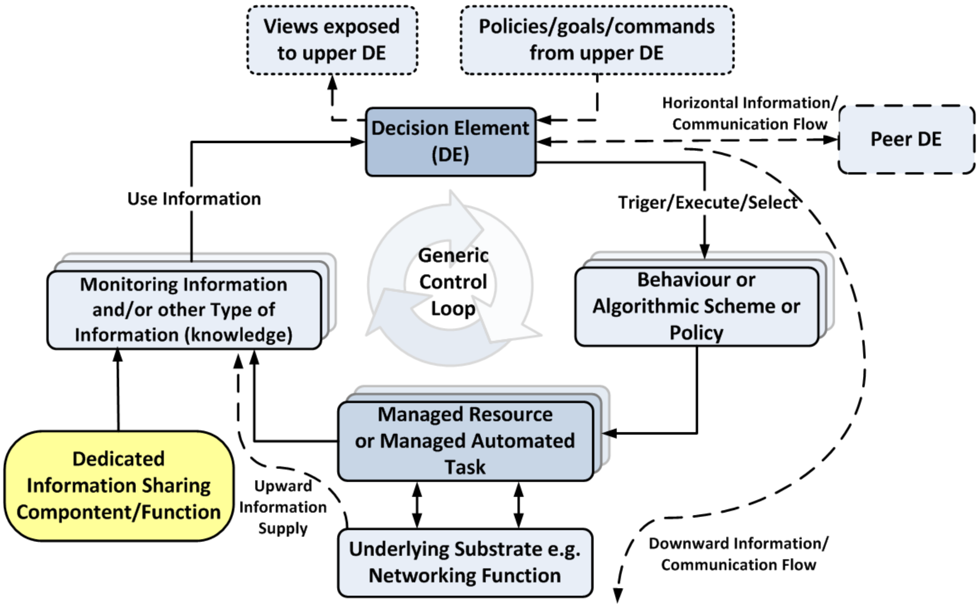


***Figure 10**. Example of generic control loop in the ETSI reference model for autonomic networking*

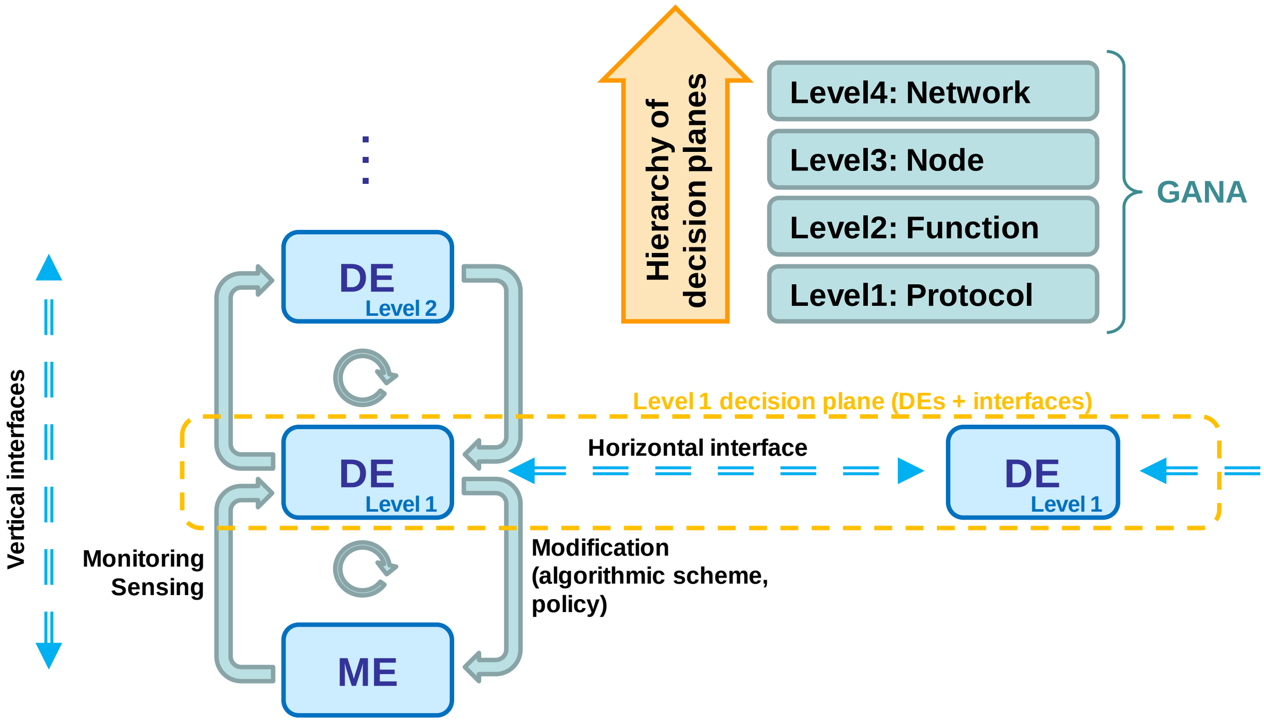


Figure 11. Hierarchy of DEs in the ETSI reference model for autonomic networking

Recently, the ETSI AFI ISG launched a Work Item entitled "Autonomicity in Wireless Ad-Hoc/Mesh/Sensor Network architectures". The goal of this Work Item is to provide an instantiation of the abovementioned reference model. Currently, AFI is in the process of defining an autonomicity-enabled wireless mesh network architecture. AGH is providing key input in this regard. presents a block diagram of all the DEs within an autonomicity-enabled mesh architecture. As future work, AGH will be involved in defining:

- specific mesh functionalities for the various DEs,
- a mapping between function level DEs and managed entities and their parameters,
- reference points between DEs,
- scenarios and use cases to illustrate the operation of the described architecture.

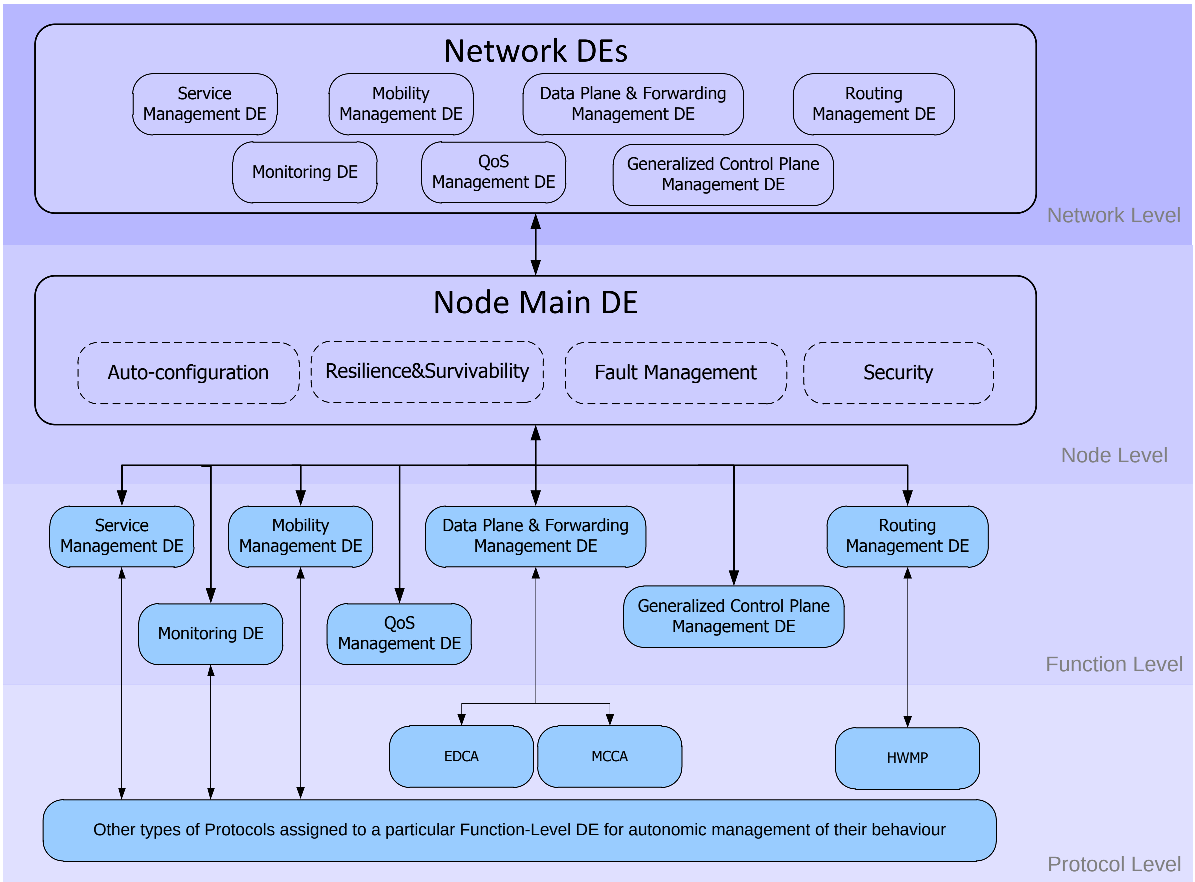


Figure 12*. *Block diagram of Decision Elements in an autonomicity-enabled mesh architecture

Since the scope of FLAVIA is in line with the scenarios and use cases considered in AFI, the project was presented to AFI members twice: during a virtual meeting (22.09.2011) and during an AFI plenary meeting at the ETSI headquarters in Sophia Antipolis, France (30.09.2011). The presentation of the project was well received and potential collaboration was discussed. In particular, it was agreed that AGH will contribute a use case based on one of the FLAVIA scenarios defined in D2.1.2.

During the AFI #12 meeting (20-21 March 2013) input from the FLAVIA project was accepted. The input is in the form of a use case/scenario entitled "Wi-Fi Network Robustness". It is based on a scenario of the same name presented in the FLAVIA D2.1.2 deliverable which covers several autonomic aspects:

- self-healing (responding to varying radio channel conditions),
- self-protection (reacting to misbehaving nodes),
- self-configuration (resolving intra-node configuration conflict),
- self-organization (establishing inter-node network configuration).

The core input is presented in . It will be included in the ETSI Technical Specification "Autonomic network engineering for the self-managing Future Internet (AFI): Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet" (to be released in 2013).

Table 2 Wi-Fi Network Robustness Scenario

Title	Wi-Fi Network Robustness (FLAVIA)
Description/Story Use Case	Modern wireless networks are unable to rapidly adapt to evolving contexts and service needs, emerging applications and use cases, due to their rigid architectural design. In order to solve this problem, new flexible solutions are appearing, which promote the concept of wireless MAC processors (WMPs). Such solutions support a vision where selected parts of the PHY/MAC resource control functionalities are easy to program. This enables the implementation and deployment of new solutions tailored to the specific environments and services they are targeting. The flexibility provided by WMPs may lead to new methods of cheating as well as intra- and inter-node misconfiguration. Therefore, new misbehaviour and misconfiguration detection solutions are required which are in line with the promoted flexibility principle of WMPs. Therefore, a flexible architecture responsible for the detection and handling of WiFi misbehavior as well as intra-node and inter-node misconfiguration is required. Such an architecture should implement advanced passive monitoring and a flexible WMP to achieve the stated goals. Passive monitoring additionally allows detecting the quality of wireless channels. The architecture should include the following components: information base (IB, a local data base containing a set of node capabilities), consistency manager (CM, module responsible for checking and correcting intra- and inter-node configurations), monitoring module (MM, based on passive scanning), and a set of services. Steps: Example 1: Wireless channel change (self-healing) 1. The degradation of the radio link quality of the current channel is detected based on the passive scanning performed by the MM. 2. MM provides a ranking of network configurations, based on available channels and data rates. 3. A wireless node switches to a channel with better quality and/or data rate. Example 2: Detection of node misbehaviour (self-protection) 1. Based on the passive scanning performed by the MM, node

<table>
<tr><td></td><td>capabilities are discovered.
2. Based on the detected node capabilities, MAC parameter values are calculated..
3. If node misbehaviour is detected an appropriate penalty scheme is employed to force the misbehaving node to start cooperating again. Examples of penalties include disassociation, blacklisting, failing to generate ACKs or even jamming transmissions.

Example 3: Intra-node consistency check (self-configuration)
1. If one of the services requests a system parameter change, the CM within a node analyses the request.
2. A local set of capabilities is generated based on the information stored in the node IB.
3. The CM verifies the internal consistency conditions and confronts it with an already configured value.
4. If the settings are consistent the CM confirms the requested parameter change.
5. If the settings are inconsistent the CM reports a conflict with an error code.

Example 4: Inter-node consistency check (self-organization)
1. Network parameters are constantly measured and the capabilities of neighbouring nodes are discovered using the passive scanning performed by the MM,
2. If misconfiguration between two nodes is detected by the CM, i.e., two nodes are determined to be using different configurations, the configuration of the misconfigured nodes is corrected by the CM.</td></tr>
<tr><td>Network Environment(s)</td><td>Wireless local area networks</td></tr>
<tr><td>Problems</td><td>1) Detecting intra-node configuration conflicts
2) Detecting inter-node configuration conflicts
3) Detecting misbehaving nodes
4) Reacting to misbehaving nodes
5) Detecting wireless link quality</td></tr>
<tr><td>Functions Impacted</td><td>The following autonomic functionalities are provided:
1) Self-healing (responding to varying radio channel conditions)
2) Self-protection (reacting to misbehaving nodes)
3) Self-configuration (resolving intra-node configuration conflict)
4) Self-organization (establishing inter-node network configuration)</td></tr>
<tr><td>Systems Involved</td><td>Wi-Fi access points and clients</td></tr>
<tr><td>Indicators / Evaluation criteria / Metrics</td><td>1) How long does it take to detect intra-node configuration conflicts?
2) How long does it take to detect inter-node configuration conflicts?
3) How long does it take to detect misbehaving nodes?
4) How long does it take to detect wireless link quality?</td></tr>
</table>

	5) What is the accuracy of the detection mechanisms? 6) Which misbehaviour reaction methods are appropriate? 7) How much resource (in terms of memory, interfaces, computational power) does passive monitoring require?
Players	Network Operators: provide wireless network Vendors/Manufacturers: provide wireless equipment
Beneficiaries	Network Operators, Manufacturers and End-Users: can easily program the selected parts of the PHY/MAC resource control functionalities

1.2.3 IEEE 802.16

In the IEEE 802.16 working group (WG), the following task groups (TGs) and study groups (SGs) are active at the time of creation of this document:

- Maintenance Task Group: this task group oversees maintenance of published standards, i.e. in order to correct ambiguities or to perform minor modifications or enhancements which become necessary from experience in network operation. The Maintenance Task Group initiated a new Project Approval Request (PAR) P802.16.1 to create a new stand-alone standard for the WirelessMAN-Advanced Air Interface, which is currently defined in the P802.16m amendment to the 802.16-2009 standard. Furthermore, the PAR P802.16Rev3 will develop a revision of the 802.16-2009 standard, containing the amendments P802.16h (license-exempt spectrum), P802.16j (multihop relay) and P802.16m, the latter without the WirelessMAN-Advanced Air Interface definition.
- Project P802.16.3: developing P802.16.3 (Mobile Broadband Network Performance Measurements). It will specify procedures for characterizing the performance of deployed mobile broadband networks from a user perspective, and specify metrics and test procedures as well as communication protocols and data formats allowing a network-based server to coordinate and manage test operation and data collection.
- Project P802.16q: developing P802.16q (amendment to IEEE Std 802.16 for Multi-Tier Networks). This amendment specifies MAC/PHY protocol enhancements for cooperation among base stations in multi-tier networks to enhance interference mitigation, mobility management, and base station power management. Enhanced base stations shall support legacy mobile stations. PHY changes to any mobile stations are out of scope. One proposal is for an Open Mobile Network Interface (OMNI) layer, which is envisioned as an adaptation layer on MAC-level to enable inter-base station collaboration between different PHY technologies [16-OMNI].
- Project P802.16r: developing P802.16r (amendment to IEEE Std 802.16 for Small Cell Backhaul). This project will develop an amendment specifying enhancements to the WirelessMAN-OFDMA air interface for effective use in wireless fixed and nomadic Ethernet transport, including small cell backhaul

applications, providing core network services to radio access networks. It will focus on backhaul operating in licensed bands below 6 GHz, in which the backhaul radio operates far enough outside the band of the small cells that interference is negligible. It will add 256QAM, 512QAM, and 1024QAM options in both uplink and downlink, with optional 4x4 MIMO in both directions, along with further enhancements that address small cell backhaul efficiency. Significant latency improvements will be attained. Enhancements to the Convergence Sublayer specifications will be incorporated as necessary for support of Carrier Ethernet 2.0 backhaul requirements.

- Project Planning Committee (PPC): The PPC is responsible for discussing and planning new potential projects within the IEEE 802.16 WG.

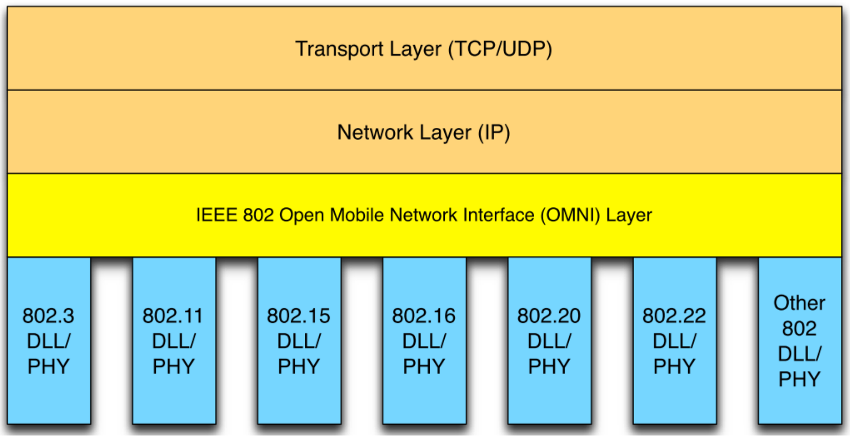


Figure 13. Scope of the envisioned OMNI MAC layer

The Machine-to-Machine (M2M) Task Group has finished developing P802.16p and P802.16.1b, and amending Std 802.16-2009 and P802.16.1, resp. The amendments enhance both existing standards for M2M communication characteristics. The main issues are congestion control, reliability and energy efficiency. The focus of this TG is on MAC layer, although minimal PHY modifications may be possible.

FLAVIA contributions to IEEE 802.16 standardization focused on the M2M enhancements. One of the main issues of M2M traffic is the potentially very large number of devices which compete for random access resources [16p-TR]. Although the 802.16m standard [16m-spec] provides mechanism for access priority, they may be insufficient to prevent a significant impact of M2M communication on human-based traffic. Furthermore, M2M traffic is aside from the estimated small traffic volume quite heterogeneous in terms of traffic characteristics. For example, smart-metering traffic is expected to occur periodically from a large number of devices with relatively low requirements on message delay and small message sizes. In contrast, traffic based on extrinsic factors such as e-health or vehicular communications occur infrequently, but possibly with high QoS requirements. Thus, the main challenges in this context are:

- prevent QoS degradation of human based communication attempts,
- enable a clean and easy solution to parameterize different classes of M2M traffic, and
- do this without the necessity to retransmit too often for power saving.

One possibility for congestion control and prioritization is to modify the ranging or bandwidth request mechanisms which introduce time dispersion either by explicit signaling or by introduction of probability factors. However, this method has the disadvantage that still all devices are competing for the same resources, and that parameterization is difficult since different device classes (including human-based communication) are interfering with each other. Therefore, the number of communication attempts is *increasing*, leading to increased power consumption of the M2M devices. Additionally, the base station has to provide additional resources quickly enough in case of sudden traffic peaks to maintain QoS guarantees, i.e. it has to estimate the aggregated traffic rate of all M2M devices and adjust the random access resources accordingly.

The concept of *dedicated resource assignments* for device groups addresses the aforementioned challenges. This means that a certain number of radio resources are exclusively reserved for M2M traffic classes or device classes, such that

- competition for random access resources is only existing *within* an M2M group for easy and isolated parameterization. Ranging and bandwidth request codes can be re-used for several groups.
- human-based communication is clearly separated from M2M traffic.
- the base station can react quickly to traffic peaks and assign resources accordingly, thus avoiding wastage of resources.
- M2M devices can be grouped according to traffic and device profiles and according to other properties such as path loss in order to enable more power-efficient communication.
- no modification of the existing 802.16m priority mechanism intended for human-based communication is necessary.

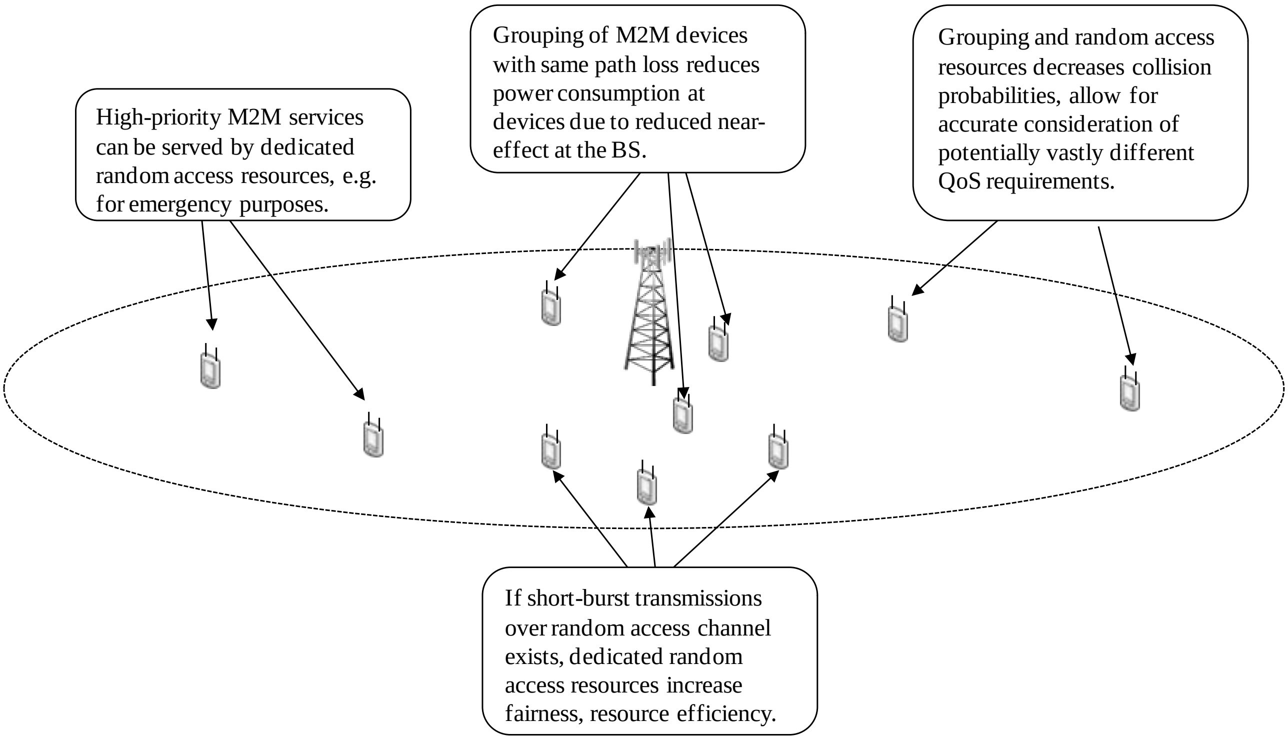


Figure 14. Scenarios for group-based, dynamic random-access resources

Figure 14 illustrates a scenario with several groups of M2M devices in a single cell. The devices are grouped according to different criteria which optimize network access for different targets, such as power consumption, priority, delay, etc. It is important that full flexibility is given to the operator to decide how and when dedicated resources are allocated to device groups.

Dedicated random access resource assignments implicitly enable time- and frequency dispersion of random access attempts. Random access resource can be allocated periodically to M2M groups with lower delay requirements such that shortage of uplink resources during peak traffic times is avoided. It is therefore equivalent to the statistical approach of reduced access probabilities, but with the advantage that interference between different groups is effectively avoided.

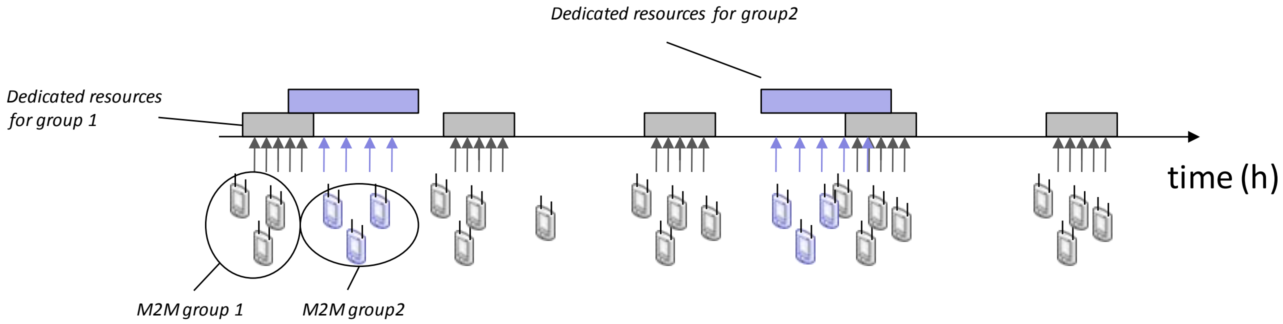


Figure 15. Example of resource reallocation

Figure 15 illustrates the proposed mechanism of dedicated random access resources on a high level. Two M2M groups are deployed in the coverage area of a BS. Both groups have a periodic traffic pattern, where the period of group 1 is smaller than the period of group 2. The base station assigns random access resources (i.e. ranging and/or bandwidth request channels) if the respective devices are going to access the channel according to their traffic pattern. Note that this also can be interpreted as an implicit access control and a method to introduce time dispersion: if devices are only allowed to access dedicated resources, resources can be assigned such that time spreading is achieved.

<u>Dedicated random access resources have been included in both standards P802.16p and P802.16.1b, initiated by a FLAVIA contribution which highlights the advantages of the concept [16p-contr]</u>. The dedicated random access mechanism is purely MAC-based, with minor modifications on the existing resource allocation for random access resources such as a "Dedicated ranging indicator" in the UL MAP Extended IE in 802.16p, and in various other MAC messages such as the AAI-PAG-ADV in P802.16.1b. In that sense, <u>the concept is a prime example of the modularity aspect of FLAVIA: For IEEE 802.16p and 802.16.1b implementations, only a small part of the implementation has to be replaced to add the functionality</u>.

1.2.4 IEEE 802.11

The IEEE 802.11 standardization activities within the project have been conducted within two Task Groups (TGs), namely TGaa defining MAC enhancements for robust audio/video streaming (802.11aa amendment) and TGs defining mesh networking (802.11s amendment), and within the IEEE 802.11 Wireless Next Generation Standing Committee (WNG SC). The activities have promoted new functionalities for IEEE 802.11 networks and focused on the following three different aspects:

- Reliable groupcast service in mesh networks.
- Mesh deterministic access (MCCA) enhanc. to provide parameter. QoS service.
- Random access (EDCA) performance enhanc. for bi-directional applications.

A considerable part of this work has been done in advance, in the first year of the project, which has allowed making contribution to TGaa and TGs before their closing.

Reliable groupcast service in mesh networks

One of the main issues of TGaa is the design of a mechanism for group addressed packets delivery with higher reliability than with today's mechanisms.

Groupcast is known to be a bandwidth-conserving technology that reduces traffic in the network by delivering the same data stream to multiple recipients simultaneously. IEEE 802.11 defines two ways of transmitting group addressed frames: broadcast and conversion to individually addressed frames. The first solution is unreliable, while the second solution is non-scalable. To improve the situation, TGaa proposes a flexible Groupcast-with-Retries (GCR) service which defines procedures targeted to make groupcast transmissions more reliable. The original GCR version was designed to be provided by the AP to associated STAs in an infrastructure BSS only.

GCR defines two retransmission policies for group addressed frames: GCR-Unsolicited-Retry, when a group addressed MSDU is retransmitted one or more times, and GCR-Block-Ack, which is an extension of the block acknowledgement mechanism to group addressed frames. In early drafts of 802.11aa amendment, the GCR-Block-Ack was based on a strict time schedule, according to which the AP polls STAs for Block Ack. Analyzing this mechanism efficiency in the scenario of a network including a long link, we found that the mechanism does not work properly and more flexibility is needed (see contribution [802.11-10/0749r0]). As a result, a majority of TGaa members preferred to replace the GCR-Block-Ack version with more flexible method, when STAs receiving groupcast packets are polled one-by-one. The method and the results of its investigation carried out in WP6 are published in [EURASIP] and [D6.2].

As mentioned above, the GCR was initially tailored to be only used in infrastructure networks. However, reliable groupcast transmission in a mesh network is even more important, since the packet loss probability increases with the number of hops. So, we have proposed a concept of GCR (initially called More Reliable Groupcast, MRG) adoption for mesh networking [802.11-10/0747r2], subdividing the problem of efficient multihop groupcast in a mesh into two subproblems: (i) reliable data delivery across single-hop wireless links; (ii) groupcast tree construction protocol.

For the first subproblem, after positive results of the strawpoll [802.11-10/0881r0] asking 'Are you interested in MRG-BlockAck procedure being supported in mesh networks?', we have developed the detailed specification of GCR for mesh based on the original GCR mechanism for infrastructure mode.

For the second subproblem, the scope of TGaa did not cover specific multihop issues, while TGs was at the stage when no significant changes to the draft were possible. So, the issue of groupcast tree construction remained unaddressed in the framework of IEEE 802 LMSC. Fortunately, Thanks to Flavia architecture flexibility, this issue is addressed in WP6 (see [D6.3]).

The original GCR mechanism was inapplicable in IEEE 802.11s mesh networks mainly due to the following reasons.

First, GCR setup procedure exploits TSPEC and TCLAS information elements. At the same time, IEEE 802.11s explicitly prohibits usage of these elements, and we propose to remove the restriction for the GCR service.

Second, GCR defines a special address concealment mechanism, which prevents group addressed frames transmitted via the GCR-Unsolicited-Retry or GCR-Block-Ack retransmission policies from being passed up the network layer of GCR-incapable STAs. In an infrastructure network, the AP is the only entity that generates and disseminates the concealment address, and it is sufficient to have only one concealment address in the network. In a mesh network, due to its decentralized nature, it is impossible to have the same concealment address for the whole network. We propose that each mesh station shall be able to generate and disseminate its own concealment address and shall keep track of concealment addresses of its neighbors.

Third, we propose to use MCCA as the transmission protection mechanism for GCR transmissions, as RTS/CTS exchange does not provide sufficient protection, as shown in our analysis in the framework of WP6 (see [D6.2]).

Fourth, GCR defines a special (GCR-SP) wake up procedure so that stations in power save mode are able to receive groupcast data not only after DTIM. At the same time, when MCCA is used for GCR transmissions protection in a mesh, a station is already woken at the beginning of each MCCAOP. Thus, GCR-SP becomes redundant, and we propose not to use it in a mesh.

To harmonize the developed normative text with TGaa members, the text was presented multiple times in multiple revisions with appropriate changes, e.g. [802.11-10/1424r10], and finally adopted in IEEE 802.11aa [802.11aa].

Mesh deterministic access (MCCA) enhancements to provide parameterized QoS service

The current IEEE 802.11 standard provides parameterized QoS service for infrastructure networks only; the service is achieved by means of HCCA channel access method with a complementary traffic stream (TS) setup procedure. The recently adopted IEEE 802.11s amendment defining operation of wireless multihop networks (mesh networks) does not include mechanisms for parameterized QoS provisioning. However, IEEE 802.11s introduces the MCCA mechanism as an optional access method that allows stations to access the channel in time intervals reserved preliminarily and called MCCAOPs with lower contention than it would otherwise be possible. During our work in WP6, we have shown that parameterized QoS service for mesh networks can be designed on the basis of MCCA by adding more flexibility to the mesh networking standard. Below we describe the changes that should be added to the standard to achieve this goal.

First, we have found that the channel access rules for MCCA-capable mesh STAs state that EDCA TXOP would not be started within tracked MCCAOPs, but do not prohibit starting an EDCA TXOP before any tracked MCCAOP reservation, even if the EDCA TXOP crosses the MCCAOP. It obviously diminishes the value of MCCA as the mean for hidden station effect mitigation and QoS provisioning. We have developed a number of innovative solutions of the problem in order to provide better coexistence of MCCA and EDCA TXOPs to improve QoS provisioning by means of MCCA. The solutions published in [ART-ME] have been presented in TGs, see [802.11-10/1360r1]. Although the proposed changes to EDCA access logic were minimal and related to MCCA-capable STAs only, i.e. the proposed changes does not touch legacy STAs, the Task Group preferred to leave the solution out of scope of the standard and gave the only hint in a single sentence that EDCA TXOPs of MCCA-capable STAs 'shall not overlap with the time periods of any of its tracked MCCAOP reservations', see Section 9.9a.1 of [802.11s].

Our further analysis of MCCA protection mechanisms has revealed other inefficiencies. We found that MCCA reservations are not fully protected from interference because of ACK-induced and Two-Hop interference problems [MCCA]. Simulation results showed that MCCA reservations should be protected either in one-hop or two-hop neighborhood from transmitter and receiver, depending on the channel conditions [MCCA-WiFlex]. Also we noticed that, according to current rules, both MCCA transmitter and receiver are protected from interference since receiver can transmit ACK frames. However, when no-ACK policy is used there is no need to protect the transmitter, and the absence of such protection increases spatial reuse and, hence, network capacity. All these factors prove that MCCA protection mechanisms are not flexible and should be changed in the following way: (i) EDCA rules shall be slightly changed to combat ACK-induced interference; (ii) new subfields describing Protection Type and ACK-policy shall be added in MCCAOP Reservation field of MCCAOPs Advertisement Information Element.

To provide a flow with Parameterized QoS service in mesh networks, we need to propagate the per-flow QoS requirements to all relay nodes in the path, i.e. the constrains on delay and PLR which shall be met on each link in the path (we refer to it as the TS setup procedure in mesh network). For that, we have developed a special signaling protocol based on the usage of 802.11 ADDTS_Request/Response frames modified slightly (see [D6.2]). However, the current standard explicitly forbids using these frames in mesh networks. So, to allow implementing the TS setup procedure in the framework of IEEE 802.11s, the following modifications should be made: (1) allow using ADDTS_Request/Response frames in mesh networks, (2) add additional fields in ADDTS_Request/Response frames and (3) change the processing logic of these frames to allow transmitting them along multihop paths.

For a given link of the path which the flow is transmitted over, we propose to set up an MCCA reservation which parameters correspond to the received QoS requirements of the flow, i.e. to move from the link-based architecture of MCCA reservations to flow-based one. The main difficulty in the approach implementation is the following. According to the standard, all frames (including QoS sensitive frames) are put in 4 EDCAF queues served in FIFO manner. When a station gets access to the channel in the established MCCA reservation, it transmits the first frame from EDCAF queues which is directed to the receiver station (the one with which this MCCA reservation was established). Therefore, the delay of QoS sensitive frames depends on the order of packets in the EDCAF queue, and strict delay requirement might be not satisfied. Furthermore, as all packets are stored in EDCAF queues, any QoS sensitive frame can be transmitted via both MCCA and EDCA and thus, PLR requirements also might not be satisfied. To solve the problem, the following modifications should be made in the standard: (i) allow to keep QoS sensitive frames not only in EDCAF queues; (ii) change access rules during MCCA reservation: during MCCAOP preference in channel access shall be given to frames of the flow for which this MCCAOP was established.

Since the TGs group working on mesh networks was closed in 2011, the presentation [IITPcont] containing all the proposals described above and also simulation results showing their effectiveness was presented at the IEEE 802.11 Wireless Next Generation (WNG) standing committee. However, these proposals did not receive enough support yet from the IEEE community. We believe that FLAVIA flexible architecture will allow to prototype and evaluate the performance of the proposed service much faster than a chipset supporting IEEE 802.11s and devices implementing new service will appear on the market soon. Based on these results we expect that the support for the proposed enhancements will significantly increase in the near future.

Random access (EDCA) performance enhancement for bi-directional applications

There are some applications that are intrinsically bi-directional, e.g., voice conversations, TCP connections. More specifically, we focus on those applications that generate the relatively short frames in (at least) one direction of the communication. In these cases, extra delays introduced by the backoff processes and the use of acknowledgements will dominate the total delay of two frames exchange.

To relax the problem, we propose to skip the two acknowledgements and one of the backoffs. More specifically, we propose that after the 1st STA has transmitted a frame to the 2nd STA, the STA does not reply with an ACK frame, but instead sends after a SIFS the Head of Line frame (if it is relatively short), which is not acknowledged by the 1st STA. Note that this does not introduce significant risks for data losses, protocol inconsistencies or unfairness, given that: (i) the first acknowledgement can be assumed to be "implicit" in the second frame (i.e., piggybacking); (ii) this second frame is transmitted after a SIFS, and therefore is protected from collisions.

To this aim, we need to extend the concept of EDCA TXOP in order to support bi-directional frame exchanges, similarly to the "reverse direction grant mechanism" of 802.11n. Using FLAVIA architecture, we have prototyped the above mechanism and presented some results providing solid evidence of the features of this mechanism in the November 2011 meeting of 802.11 Wireless Next Generation Standing Committee (see [wng-flavia]).

In particular, according to the results obtained for the case of the mixed scenario with voice and data, the "capacity region" (i.e., the maximum number of flows that can be supported) is substantially extended, practically doubling the maximum number of voice conversations that can be supported in the network.

After the presentation and the useful feedback received we concluded that the FLAVIA framework is very effective to present and better defend new mechanisms to the standard community.

1.3 Exploitation Activities

In the following we provide a summary per partner of the exploitation activities performed during the project.

1.3.1 Industrial Partners

Alvarion

Alvarion intends to obtain as main outcome of the project a new software platform more open and more flexible and generic enough to allow its utilization with minimal changes in multiple technologies.

Alvarion's scheduled systems are nowadays based on WiMAX IEEE 802.16e but the Company will need to face in the future scenarios in which 806.16e deployments will coexist with new standards like IEEE 802.16m or TD-LTE. This project will provide Alvarion with new tools and knowledge that will pave the way for such future challenges.

FLAVIA's approach based on modularity and flexible MAC will enable Alvarion to implement the support for an enhanced Video Traffic QoS. Alvarion is developing such new feature for unlicensed WiMAX bands. This can open interesting new markets to our scheduled systems using unlicensed spectrum including video-surveillance, smart grids, eHealth and other vertical applications.

MobiMESH

The main goal for MobiMESH in the FLAVIA project was to develop a flexible and virtualizable architecture to be used into the wireless card on top of mesh nodes in order to easily support multiple services and share the network resources among several applications with heterogeneous Quality of Service requirements, as illustrated in Figure 15.
Therefore, the experimental activity has been focused mainly on the definition and implementation of the services that provide the flexibility feature of the FLAVIA architecture.

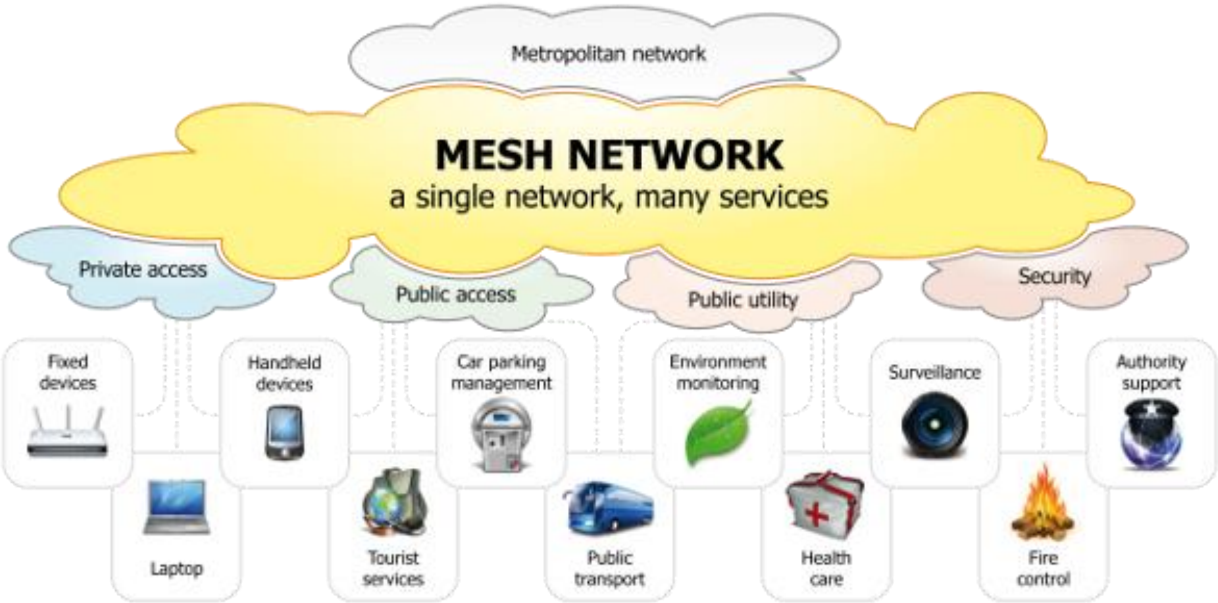


Figure 16 - MobiMESH flexible architecture

Some key elements of the FLAVIA framework developed during the project have been integrated into the MobiMESH architecture to support the different services in municipal networks and increase the flexibility of the system.

Significant effort has been devoted also to the study and development of more accurate monitoring techniques to find the best nodes configuration according to the network status and the external interference.
Within the FLAVIA architecture, a distributed service to coordinate and schedule the passive and active monitoring tasks has been developed to improve the accuracy of link sensing techniques used for estimating the channel link quality.
This effort has led to the implementation of SuPerSense, a new service that integrates most of the proposed approaches to detect statistical errors and estimate the network status (e.g., traffic load, interference caused by both the internal and external sources).
Figure 16 illustrates the MobiMESH Network Management Server that has been extended to provide the information collected through SuPerSense and reconfigure the network on-the-fly to meet the QoS requirements defined by the network administrator.

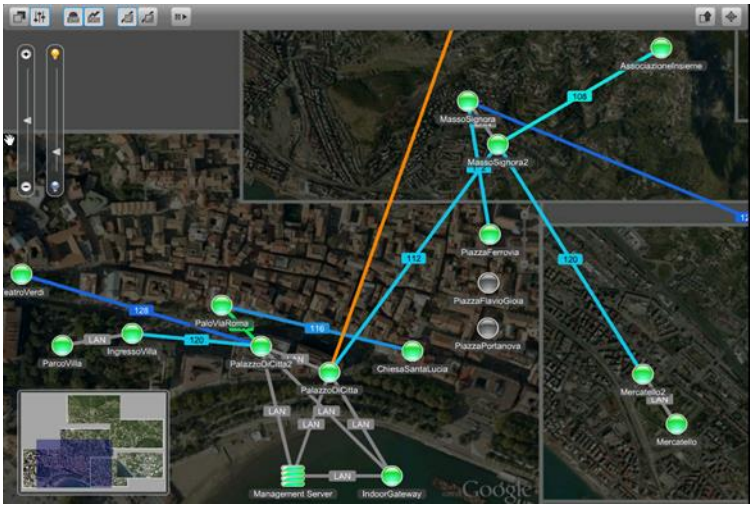


Figure 17 - MobiMESH Network Management server

Finally, network operators can greatly benefit from the information exported by SuPerSense. Indeed, such information can be used to design new routing mechanisms and metrics to select the best network paths according to the application needs. As an example, MobiMESH has developed a radio and rate-aware routing protocol to reduce the intraflow and interflow traffic interference.

<u>*NEC*</u>

FLAVIA's architectural results have been used at NEC to get quantifiable answers about the level of flexibility and programmability that could be introduced in the architecture of future wireless products. These findings have been considered for NEC products roadmap evolution analysis.

Significant efforts were devoted to the 3GPP and IEEE 802.16 standardization contributions where several approaches designed in FLAVIA were promoted for their incorporation in standards and subsequently in NEC's products. Several of the enhancements proposed both to 3GPP and IEEE 802.16 have been accepted and became part of standards specifications.

The most prominent example of adoption in NEC products of FLAVIA's concepts is the incorporation in NEC's LTE Small Cells product line of RAN Virtualization concepts. Key RAN Virtualization features along with future ones were advertised at the last Mobile World Congress in 2013 and summarized in a white paper publicly released in March 2013 with major contributions from NEC's FLAVIA members [NEC-White Paper].

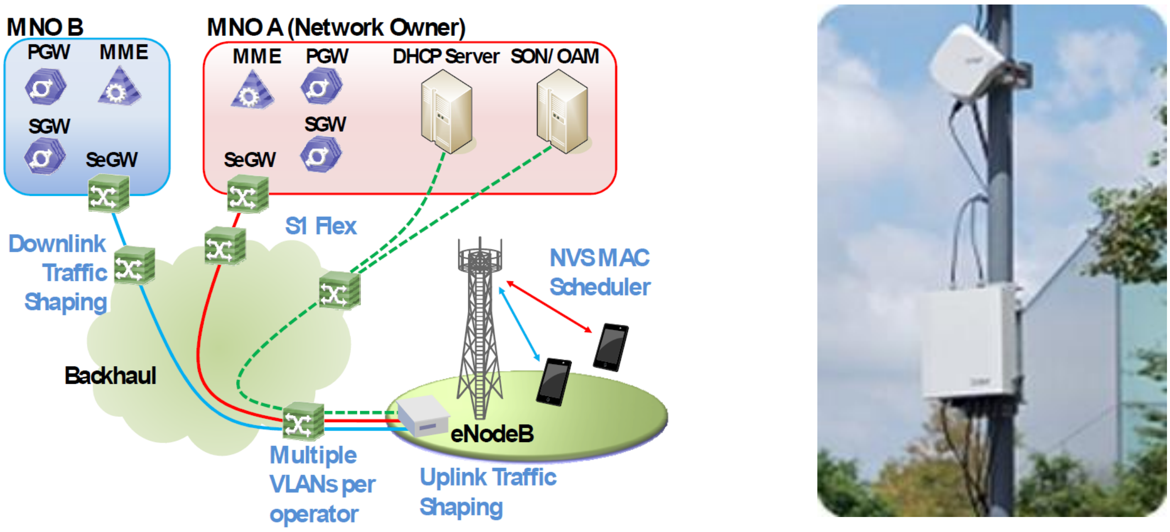


Figure 18. NEC's RAN Sharing Small Cells Solution.

Finally, key technical innovations were considered for patent applications to increase NEC's IPR protection in the base station programmability area. During the project duration NEC filed two patent applications in the LTE area.

Telefonica I+D

The main objective of TID in FLAVIA is to define a software framework to enable flexible programming of WLAN devices. This will enable TID to create new and innovative services to be offered to Telefonica customers in the future. As an example, we are working in WLAN backhaul bandwidth aggregation using a single radio client card and we are considering large scale testing. As well, we are studying implementing the feature into routers to offer similar functionality to device with closed drivers or very strong integration (tablets, phones…).

As a research center, we are also focused on publications and pushing forward the state of the art. In this scope, we have written a top tier conference paper during the first year of the FLAVIA project which will be presented during the second year. This publication will give high impact and visibility of both TID and FLAVIA on the research community. As well, we are working on another publication to present the approach we are considering to bring aggregation technology benefits to a larger set of devices.

In addition, the opportunity to collaborate with different research institutions from many other countries triggers new collaboration opportunities for future research projects.

Following our initial plans of exploiting backhaul aggregation, we have been conducting internal tech transfer of the FLAVIA virtualization technology on consumer hardware. The first output is BeWiFi, a solution for increasing speed and mobility of wireless access by reusing spare bandwidth. It is designed as an over the top solution (i.e. supplemental routers) to be deployed at home of users.

A website has been created (http://www.bewifi.es), as well a Twitter account (https://twitter.com/Be_Wifi) for dissemination and vulgarization of the technology. To this purpose, a high-level video (http://vimeo.com/61090627) is explaining the concept for customers.

Figure 18. One of the visual for BeWIfi

As well, a trial has been started in Roquetes, an area of Barcelona. The kickoff of the event has been the public recruitment of customers for the trial. The trial is scheduled for the months of May and June 2013.

Figure 20*. *Trials in Roquetes, Barcelona

Figure 21. Packaging for Bewifi

<u>Sequans</u>

The main objective for Sequans Communications in FLAVIA is to develop a software framework in the user terminal (typically a USB dongle connected to a regular laptop) that is flexible and generic enough to allow the development of applications on the host side, with easy interaction with the 4G chipset in the dongle. As an example, this framework would allow to gather measurements from the radio interface or to control the dongle. This generic and flexible framework will be defined in a way that it could be applicable both for WiMAX or LTE user equipment.

In terms of exploitation, Sequans plans to leverage this framework to improve the debug and/or monitoring capabilities of the user terminal. Indeed, an home-made tool is being developed based on the outcome of the FLAVIA project. The tool is internally called *Debug and Monitoring tool (DM tool)*. The outcome of the FLAVIA project would be thus to accelerate the development of Sequans reference designs and to ease IOT with base station vendors. Two DM tools are actually developed: a WIMAX one and a LTE one, both reusing as internal software skeleton the philosophy of FLAVIA flexible architecture.

Extending this framework, especially to report measurements information could be done as well to validate in prototyping new concepts e.g. of scheduling by base station vendors.

The DM tool has to be used in conjunction with a 4G dongle (either WiMAX or LTE) and is able to display the events generated by the dongle (actually, each technology has specific events). The ***Figure 22*** illustrates a 4G dongle connected to a laptop.

Figure 22*. *Illustration of a 4G USB dongle connected to a laptop

The Figure 23 depicts the main window of the LTE DM tool. The layout of the window is quite simple: a command line is used to interact with the dongle and enter the commands; a window displays the events and the messages responses coming from the dongle. In the context of the FLAVIA project, more advanced display architecture has been investigated in a joint collaboration with another partner, but has not been yet integrated in Sequans internal tool.

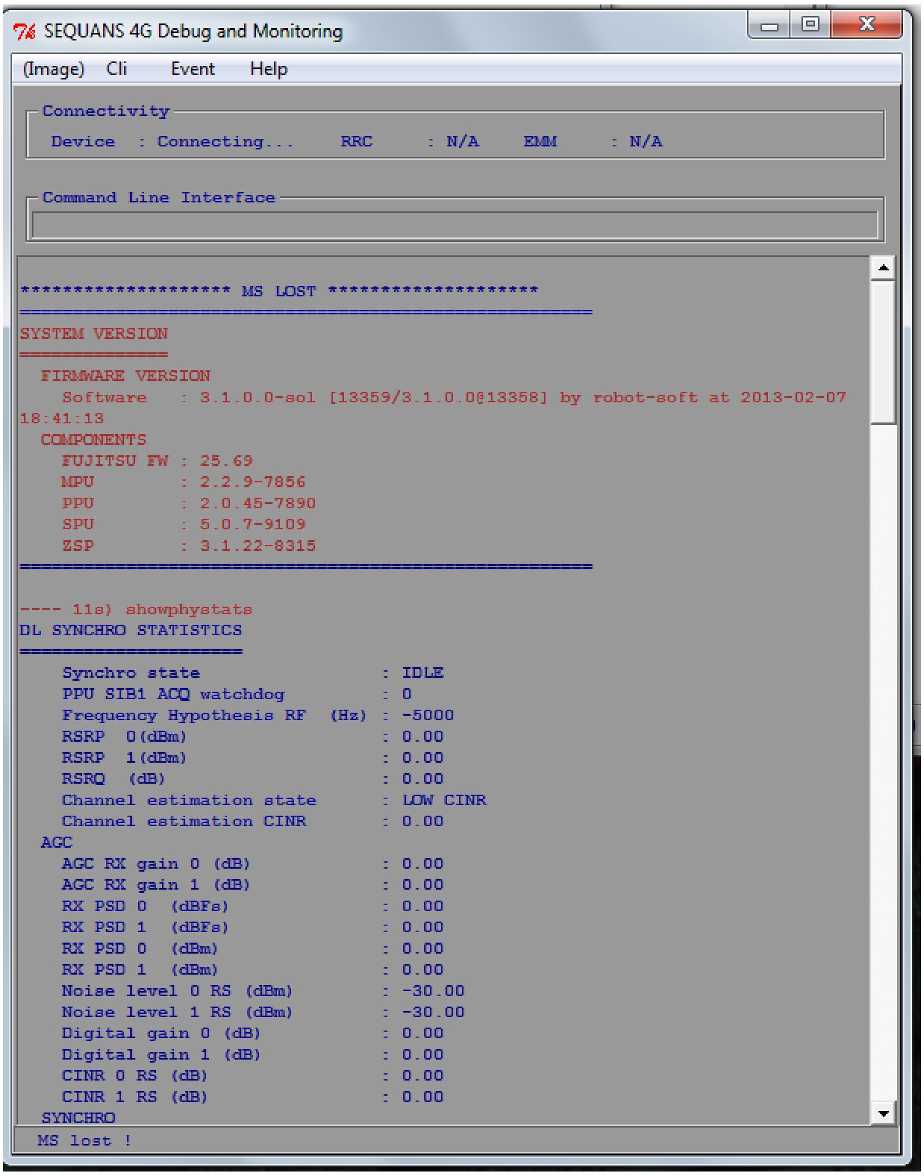


***Figure 23**. The main window of the LTE DM tool*

The measurement framework developed thanks to FLAVIA has thus been reengineered and extended inside Sequans to develop the DM tools. Although it does not aim to become a commercial product, one can say that such tool is of great help for internal development and debugging.

As this framework consist mainly on software development, it is unlikely that the activity of Sequans in FLAVIA will generate IPR. In case the technologies coming from the project can be patented, then Sequans will support the redaction and submission of patent filings. For innovation generated by the collaboration of partners, co-authored patent filing will be created. The detailed rules to write and access to IPR generated in Flavia context are described in the Consortium Agreement.

1.3.2 Research Centers

IMDEA

The work being carried out in FLAVIA is bringing publications in international conferences (e.g., INFOCOM, CoNEXT, WoWMoM, e-Energy, WCNC, FUNEMS) and journals (e.g., IEEE/ACM Transactions on Networking, IEEE Communications Surveys and Tutorials, COMNET, COMCOM, PMC), apart from other dissemination activities. Two undergraduate and two graduate students have already finished their corresponding final projects in topics related to FLAVIA project, and one Erasmus Placement student is devoted to testing the FLAVIA WMAC architecture, which has enormous teaching possibilities, while a second Erasmus Placement student has developed his thesis working on ICIC solutions for schedule-based systems. The researchers working with IMDEA are planning to continue the work carried out in FLAVIA even after the end of the project, and submit more work to conferences and journals during the next year.

FLAVIA's work has helped to increase IMDEA's technical leadership in a three-fold way. First, currently four students are pursuing their PhD in activities closely related to the project, namely adaptive mechanisms to optimize WLANs, prototyping and assessment of a flexible software/firmware platform that support ad-hoc modifications to 802.11 standard, development of new architectures for scheduled systems (e.g., WiMAX and LTE) and for the coexistence of LTE and WiFi cells, and developing new, power-aware schemes to improve energy efficiency. Second, under-graduate students have deployed a medium-sized testbed assessed the performance of traffic generators, characterizing the transmission mask of 802.11 equipment, and the feasibility of adaptive power configuration schemes. Third and finally, ongoing FLAVIA activities is helping IMDEA to find new collaboration opportunities with FLAVIA and other European partners, increasing the institution's visibility and the exchange of ideas (and even personnel) between countries. In this collaborative framework, IMDEA and other FLAVIA partners have worked jointly on the preparation and submission of new project proposals.

IITP

In addition to academic research, standardization activities, and related publications, IITP RAS serves as a maintainer of several modules of popular NS-3 discrete-event network simulator (http://www.nsnam.org/). The work being carried out in FLAVIA helps us promoting flexible protocols and approaches into NS-3 simulator, as with FLAVIA architecture, such mechanisms will be possible to implement in the future, which, in turn, attracts more attention to performance evaluation of such mechanisms. In particular, we are about to release in NS-3 the model of mesh deterministic channel access method (MCCA) defined in IEEE 802.11s standard, including mechanisms which was developed in WP6 to provide parameterized QoS service in mesh networks. In addition, IITP uses the knowledge and experience obtained throughout the project to improve its bachelor and master student courses, as well as postgraduate study courses. Specifically, one of the PhD students deeply involved into FLAVIA project is preparing his PhD thesis based on the results obtained during his work in the FLAVIA project. Of course, participation in the FLAVIA project helps IITP RAS, as the institute of the Russian Academy of Science, to proactively collaborate with leading European scientific centers and industrial partners.

1.3.3 Universities

CNIT

CNIT work has been focused on the exploitation of the technical developments at both academic and scientific level. One of the main outcomes on the scientific side has been the development of an open source release of the Wireless MAC processor published on the FLAVIA website: here the main components (editor, bytecode manager, and related MAC examples) can be downloaded and a manual to guide the programming is provided as well.

A basic plan for CNIT is to provide the WMP and the accompanying software libraries as a research and teaching toolbox for the benefit of research fellows and faculty colleagues. Since open source access to the code requires some initial installation which, even if not particularly difficult for a researcher in the field, may nevertheless prevent large scale dissemination in the teaching community, CNIT is currently planning (and analysing the underlying legal issues) how to distribute an already assembled package (similarly to how teaching and research boards such as NetFPGA are actually shipped), including the WMP firmware already preinstalled on a commodity commercial platform.

In parallel as relevant results of the work, CNIT has produced two important patents from the scientific work realised within FLAVIA. The first "Method of changing the operation of wireless network nodes" has been registered in the USA on May 31, 2013, owing to the fact that USA is the only country which permits filing patents even after an idea has been published. This USA patent mainly deals with the MAClet mechanism (introduced in the CONEXT paper by the patent inventors) for remotely programming the behaviour of a wireless node by means of the WMP programming interface and a central controller. The idea is sending the MAC program over the air in special packets called MAClets and activate them dynamically on the basis of the commands sent by the MAClet Controller (which typically is installed at the Access Point). The method has several interesting use cases, among which the possibility to support an advanced form of virtualization.

The second has been registered in Italy on April 8, 2013, and is a "Method of processing data packets and wireless network node". This patent deals with a novel mechanism for programming a self-adapting MAC scheme (called 'policy') on the wireless nodes. A policy is a meta state machine including one or more MAC protocols that can be configured for managing the access operations of one or more MAC queues. In other words, different queues can simultaneously adopt different access rules according to the MAC protocol they are linked to. Moreover, the transitions between the MAC protocols can program a MAC switch in case of special network events or monitoring results, for performing an autonomous MAC reprogramming with very critical time constraints, without any explicit command sent by the controller.

AGH

During its involvement in FLAVIA, AGH University of Science and Technology has significantly improved its expertise in the area of IEEE 802.11 standards including analysis and optimization of WLANs as well as on their deployment. AGH installed some IEEE 802.11 access points with QoS guarantees for students and employees at Department of Telecommunications. Three different methods for providing QoS were implemented: at the data link layer (using IEEE 802.11 EDCA protocol), at the network layer (using HTB queuing disciplines), and at the both mentioned layers (using hybrid solution). A new algorithm, which allows for remote configuration of QoS parameters in wireless clients has been developed, implemented and successfully tested. The complete AP software was uploaded to the MIKROTIK Routerboard 411 platform equipped with single miniPCI WLAN card and two external antennas. All the introduced mechanisms allow for a very precise QoS control in infrastructure-based IEEE 802.11 wireless local area networks.

In the case of FLAVIA, AGH is committed to spreading some of the knowledge and experience developed throughout the project to students through the lectures, seminars, and postgraduate study courses. More specifically, the interesting and important results obtained throughout the project will be integrated into some content relating to wireless networks. Currently three students (two PhD and one MSc) are involved in activities which are closely related to the FLAVIA project. First PhD student is implementing IEEE 802.11aa standard including credit based shaper algorithm in NS-3 simulator. Second PhD student is implementing in NS-3 a novel multirate algorithm for IEEE 802.11 based networks. MSc student is working on the partial implementation of IEEE 802.11aa in the commercially available WLAN network cards. Moreover, the FLAVIA project helps AGH University of Science and Technology in a collaboration with leading European universities, manufacturers and operators. A new bilateral cooperation project between AGH and CNIT financed by the Italian Ministry of Foreign Affairs and Polish Ministry of Science and Higher Education within the CANALETTO Programme and entitled "ADvancedwifi networks for HOme Customized applications (ADHOC)" (2013-2015) has been approved. The project, which can be considered a niche-scenario extension of FLAVIA, deals with the analysis of solutions for adapting home ad-hoc networks to different application requirements and environment conditions.

Ben Gurion University

Given the more mature FLAVIA architecture, BGU continued to explore novel solutions supported by this architecture for the next generation broadband wireless networks. Specifically, using the open source firmware adopted by the project, BGU implemented a network coded unicast downstream traffic as well as a distributed opportunistic scheduling. Besides two faculty members, BGU team comprises one post-doc and four students (one Ph.D., one M.Sc. and 2 undergraduates) which are working on topics that are within FLAVIA projects, namely, distributed intercell interference mitigation, power save, distributed opportunistic scheduling and network coding.
In addition to its ongoing collaboration with FLAVIA partners and in particular IMDEA, BGU also collaborates with groups outside the projects on enhancements that are made available by to the FLAVIA architecture. Specifically, on collision avoidance without control messages, in collaboration with Rice Networks Group (accepted for publication in Mobicom 2012), as well as on power save mechanism their validation and implementation in cooperation with Intel, Israel.

National University of Ireland, Maynooth

NUIM has demonstrated at IEEE WoWMoM the node policing mechanism that builds upon the flexibility offered by FLAVIA and the open source firmware adopted by the project to restore fairness in 802.11 networks. Plans for IP patenting are in progress with the commercialization office of the university.

A collaboration with CNIT is in progress for the development of a multi-hop MAC paradigm that relies on the functionality provided by the WMP and Broadcom firmware. There are plans for a visit of a NUIM post-doc at University of Brescia and a student enrolled at University of Brescia has been co-opted in this project. This will further disseminate the results of FLAVIA.

The work on mobile access of wide-spectrum networks has been presented at IEEE INFOCOM conference, as well as in seminars given at TU Darmstadt, NEC Laboratories and Paris-Descartes University. Discussions focused on the wireless MAC processor and the GUI editor have taken place with the SEEMOO group at TU Darmstadt and the

LRI group at Paris-Sud University, the parties showing interest towards utilizing these developments for teaching and PhD training purposes.

At NUIM Maynooth, a student and a post-doc are currently investigating the possibility of using the FLAVIA WMP developments with Broadcom cards for improving the performance of power-line communications.

1.3.4 Patent Applications

"Method and single radio station for managing station throughputs from a wireless multiple access points backhaul"

Aggregating multiple 802.11 Access Point (AP) backhauls using a single-radio WLAN card has been considered as a way of bypassing the backhaul capacity limit. However, current AP aggregation solutions greedily maximize the individual station throughput without taking fairness into account. This can lead to grossly unfair throughput distributions, which can discourage user participation and severely limit commercial deployability. Motivated by this problem, we present THEMIS, a single-radio station that performs multi-AP backhaul aggregation in a fair and distributed way, without requiring any change in the network. We implement THEMIS on commodity hardware, evaluate it extensively through controlled experimental tests, and validate it in a deployment spanning 3 floors of a multi-storey building.

"Making WiFi Backhaul aggregation practicable"

Aggregating WiFi backhaul bandwidth has been explored using clients able to simultaneously connect to multiple access points (APs). However, such solutions require the modification of the driver of the end user's WiFi devices. This requirement prevents these solutions from being deployed widely since modifying the driver of every single WiFi device is infeasible. We introduce AGGRAP, a single-radio AP able to aggregate the spare bandwidth of neighboring Aps to increase its users' connectivity speed. AGGRAP is able to simultaneously act as an AP for its clients and as a station to collect bandwidth from other WiFi networks regardless of their frequencies. We show the benefits and limitations of performing bandwidth aggregation with a single-radio AP and propose a system architecture.

"Admission and Congestion Control Exploiting Additional Buffer- and Data-Process-Information"

In essence, the filed patent claims a method to indicate the end of a transmission by the UE towards the eNB in order to be able to timely release resources of low-payload connections. The patent further details how this information may be acquired, how the bit may be set and how the network may react upon reception of this indicator.

"RAN Sharing – Load Balancing"

Cellular network sharing is a key building block for virtualizing mobile networks in the future in order to handle the explosive capacity demand of mobile traffic, and reduce the CAPEX and OPEX burden faced by operators to handle this demand. This invention addresses one of the technical challenges that arises in this scenario by defining a solution to enable a Hosting RAN provider and/or participating operators to define policies for sharing the capacity within the cells of a shared RAN and control methods to enforce the fulfillment of the RAN Sharing agreements.

"Method of changing the operation of wireless network nodes"

The operation of a wireless network node depends on the specific communication protocols used by the node for communicating with other nodes at different levels. One of the levels is the "data link" layer and comprises a sub-layer called "MAC" layer. A change in the communication protocol corresponding to e.g. the MAC layer will result in a change in the operation of the wireless network node. In the present wireless network node the MAC protocol is implemented through an extended finite state machine executed by the node. In order to change the operation of the present wireless network node (e.g. a station), the following steps are carried out: establishing a wireless connection between the present wireless network node (e.g. a station), and a remote wireless network node (e.g. an access point), sending one or more data packets containing a coded extended finite state machine corresponding to a specific MAC protocol through the wireless connection from the remote wireless network node to the present wireless network node, sending an activation command from the remote wireless network node to the present wireless network node through the wireless connection for activating the specific MAC protocol. This may be done during normal operation of the present wireless network node

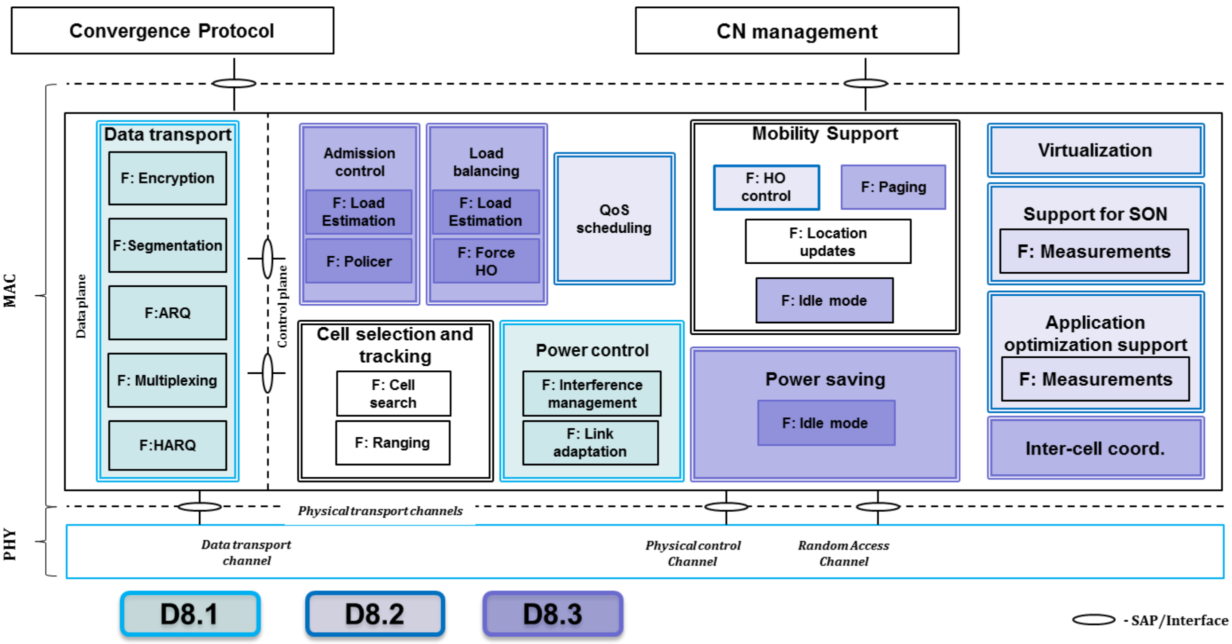
"Method of processing data packets, including transmitting them using more than one MAC protocol, and wireless network node"

According to the method of processing data packets, a wireless network node:
A) receives the data packets, B) classifies the received data packets according to one or more classification criteria, and C) transmits the classified data packets using a MAC protocol related to the classification of the packets to other wireless network nodes. Typically, at least two classification groups are provided for carrying out step B and at least two MAC protocols are provided for carrying our step C; in step C, switching occurs between the at least two different MAC protocols in real time.

2 FLAVIA Architecture: LTE Applicability Assessment

2.1 Review of FLAVIA Architecture for LTE Applicability

In previous deliverables (D8.1 and D8.2) the generic FLAVIA architecture as well as its detailed specification for the scheduled systems case (D3.1) was reviewed with respect to its applicability to future 3GPP systems. In this deliverable we complete this review by considering a last set of functions of the FLAVIA architecture considered of major relevance. The following figure summarizes the different functions covered in the three deliverables during the project.



Next, in the following subsections the different functions covered in D8.3 with respect to their LTE applicability are described.

2.1.1 Load Balancing

Load Balancing is a key optimization function included in the set of self-organizing networks capabilities of 3GPP systems. As described in Technical specification 32.522 the load balancing objective is to cope with undesired traffic load distribution and to minimize the number of handovers and redirections needed to achieve it [3GPP TS 32.522]. Two main functions are defined:

- LB Monitor Function: This function is used for monitoring the load balancing optimization (e.g. Monitoring related performance counters or alarms).

- LB Policy control function: This function is used for configuring the load balancing optimization policies.

Their integration in 3GPP systems is depicted in the following figure where EM, DM and NM stand for element, domain and network manager, respectively.

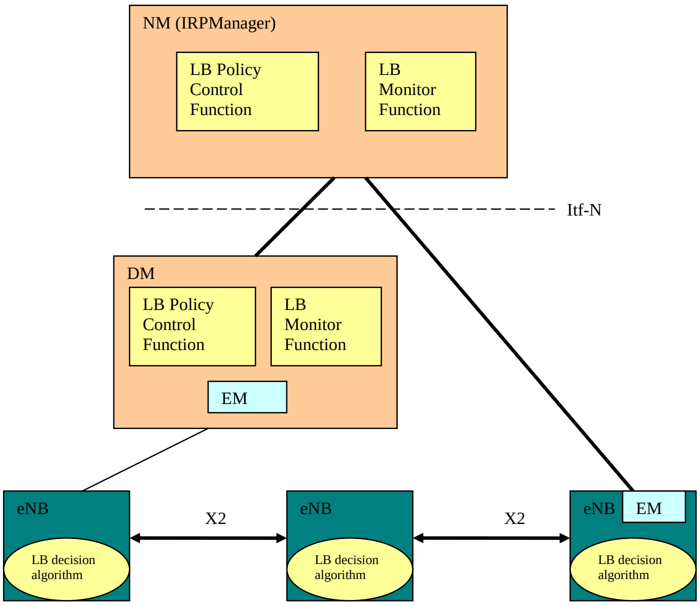


Figure 24. 3GPP Load Balancing Logical Functions Location [3GPP TS 32.522]

The load balancing functionality shall monitor input data such as performance measurements, fault alarms, notifications, etc. After analyzing the input data, optimization decisions will be made according to the optimization algorithms. Corrective actions on the affected network node(s) will be triggered automatically or manually when necessary. The Integration Reference Point Manager (IRPManager, typically a network management system) shall be able to control the self-optimization procedures according to the operator's objectives and targets [3GPP TS 32.521].

Several performance metrics and optimization targets might be considered by the load balancing algorithm. Examples include RRC connection establishments failure rate, E-RAB setup failure rate, RRC connection abnormal release aate, E-RAB abnormal release rate, rate of failures related to handover, etc. An exhaustive list can be found in [3GPP TS 32.522]. Based on this information load optimization targets may be achieved by optimizing mobility settings as handover and/or idle mobility configuration as specified in [3GPP TS 36.331].

In deliverable D8.2 we reviewed LTE's handover functionality and its applicability to FLAVIA's framework. Special mention deserves here the capability in 3GPP systems of defining bias values which allows for cell range expansion (CRE) as in the case of heterogeneous networks. This capability can be exploited for load balancing.

By reviewing the load balancing function interfaces and primitives defined for IEEE 802.16 in deliverable D3.1.1 Section 3.26 we can conclude that the architecture and primitives could be readily applied for basic load balancing in the LTE case. As an example Primitive *LADA_IAP5_estimated_MCS_REQ/REP* would be used for requesting the regular channel estimation measurements from UEs. Primitive *LOBA_IAP5_execute_REQ/REP* would be used for triggering load balancing upon overflows initiated by the measurements from the monitoring service. Primitive *MOSU_IAP5_trigger_HO_REQ /REP* would be used to request handover initiation. Full LTE support would require an extension of some of the primitives, especially in the UE measurements case to adapt to the specific metrics defined in the 3GPP specifications.

2.1.2 Paging

In this part, we provide a more detailed description of the function “Paging” which is part of the module “mobility support.” In mobile networks, user terminals may basically be in two states: IDLE state or CONNECTED state. CONNECTED state refers to an active connection with the serving base station while IDLE state refers to an energy-efficient mode where no pro-active communication takes place. Instead, the user terminal reads regularly a dedicated channel in order to determine whether the network is attempting to establish an active connection with the user terminal. This process is referred to as paging. In the following, we outline the commonalities and differences of the paging process in 3GPP LTE and IEEE 802.16.

In 3GPP LTE, the Mobility Management Entity (MME) initiates the paging of a user terminal in order to re-establish the corresponding bearers, e.g. if downlink data is available for the UE. The paging process is initiated by sending a PAGING message to all base stations in its tracking area which are then broadcasting the paging request. Each MME maintains a tracking area to which one or more base stations are assigned. Upon leaving CONNECTED state, a user terminal registers with a MME and its tracking area. As soon as a UE leaves this tracking area, i.e. entering the coverage of a base station which is not assigned to the same MME, the user terminal needs to send a tracking area update. This ensures that the network always knows the area (i.e. set of base stations) where a user terminal is located in order to page efficiently user terminals. Upon receipt of a paging message which contains the user terminal’s SAE Temporary Mobile Subscriber Identity (S-TMSI), the user terminal performs a RRC connection re-establishment. In general, user terminals may be paged in order to inform them about available downlink data, but also to inform them about changes of the network configuration (*systemInformationModification*). Once the UE receives such an indicator, it will acquire the updated system configuration. Furthermore, the paging process is used for Earthquake and Tsunami Warning System (ETWS) and Commercial Mobile Alert System (CMAS) messages.

In order to page a user terminal on the air interface, each cell has a default paging cycle but may also configure user terminal-specific paging cycles (of which the user terminal will use the one with the highest frequency). At a paging occasion (PO), the network will then submit a paging request on the PDCCH which needs to be scanned by the user terminals. The paging cycle and paging occasions are configured by the network which is therefore informed about the timeslots when a user terminals is listening on the PDCCH. This also includes support of discontinuous reception (DRX). Finally, the resources for the paging channel are assigned dynamically and may vary depending on the network's preference based on current load and configuration.

In IEEE 802.16, paging is performed similarly. IEEE 802.16 defines paging controller entities which are part of the network control and management system (NCMS). Each paging controller maintains a paging group consisting of a set of base stations. If a user terminals needs to be paged, the paging controller instructs all base stations within its paging group to issue a MOB_PAG-ADV MAC message, which is broadcasted by each base station. Each mobile station is listening in deterministically defined intervals (paging listening interval) which alternate with paging unavailable intervals (PUI). Both are known to the network and the mobile station which allows to address deterministically a mobile station. However, the network may define specific paging offsets for each mobile station which leads to shifted paging listening intervals. Similar to 3GPP LTE, IEEE 802.16 also supports paging to groups of mobile stations. Depending on the message itself, the mobile station will either perform a location update or a network re-entry.

In FLAVIA, this paging function can comfortably be implemented by providing an interface from the mobility support module towards the upper layers, in particular CN management (MME in 3GPP LTE and NCMS in IEE 802.16). This interface defines the user terminals that need be paged. The actual implementation of the paging process is equivalent in both 3GPP LTE and IEEE 802.16, i.e. definition of sets of user terminals that are paged, the definition of paging occasions, and the definition identifiers to address the paged user terminals. The only difference is the actual content of the paging message which needs to be performed by the wireless processor. However, the content of paging message is very limited and will therefore not require significant overhead for the wireless processor.

2.1.3 Power Saving

In [FLAVIA D3.1.1 figure 6], it was presented a first MAC decomposition in elementary functionalities for scheduled-based systems. Among these services, *scheduling functionalities* have been taken into account because of their central role. In the present paragraph we consider customization for 3GPP LTE and evaluate the impact of programmable scheduling on the three main FLAVIA pillars: *modularity, flexibility, and virtualization*.

MAC scheduling is strictly related with virtualization, depending on the way resources are assigned to multiple upper-layer entities. MAC scheduling contains heterogeneous functions such as frame building management, resource allocation and exploits data from other services, e.g., taking into account fractional frequency reuse policies. MAC scheduling gets allocation restrictions from *inter-cell cooperation and coordination* in order to employ resources while preventing interferences among nodes. It also gets inputs from scheduling strategies and QoS scheduling.

MAC scheduling decides about frame resources. As recently appeared [Showk2011], LTE functionalities can be divided in several eXtended FSMs communicating each other running (eventually) in parallel. MAC, RLC, PDCP decomposition in XFSMs is used in [Showk2011] to implement a load balancer on multi-core LTE mobile terminals, while in the present context we consider the MAC scheduler as a 'resource balancer' instead of the load balancer indicated above. Currently in LTE there is a single MAC entity modeled with a single state machine, the FLAVIA flexible architecture propose several XFSM for each MAC scheduling policy.

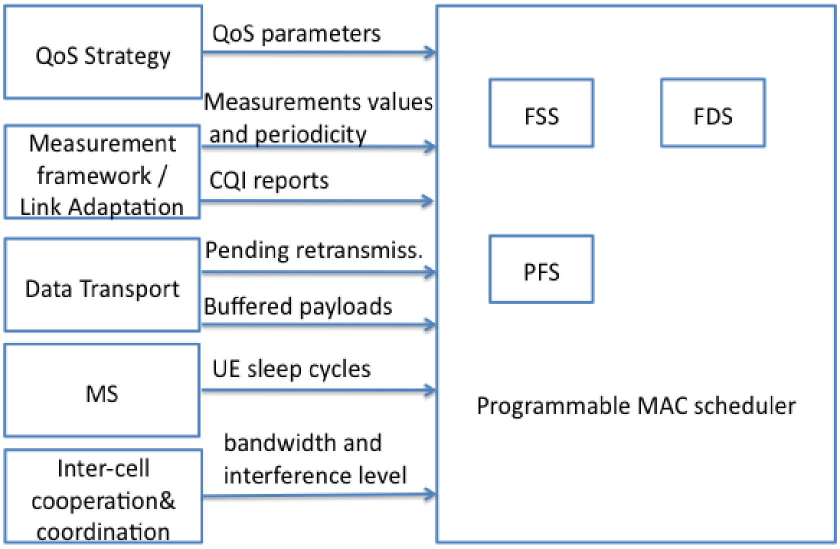


Figure 25 Programmable LTE scheduler and its interactions with other services

The LTE MAC layer includes mapping between logical channels and transport channels and multiplexes/demultiplexes the RLC PDUs into/from transport blocks.

In LTE, the scheduling functionality is performed at the eNB where resources in time and frequency are assigned for both uplink and downlink at each TTI (Transmission Time Interval) via the C-RNTI Cell Radio Network Temporary Identifier.

The MAC scheduler selects the best multiplexing for UE considering external data/parameters as shown in the figure above.

Downlink LTE considers the following schemes as a scheduler algorithm [Ergen], as shown in figure:

- FSS: Frequency Selective Scheduling assigns transmission resources to a user using the selective resource blocks to offer the best performance. Channel-side information is necessary for FSS and it can increase capacity over TDS (Time Domain Scheduling). This type of scheduling may be used at higher speeds, at cell edges, or for low overhead services.
- FDS: Frequency Diverse Scheduling does not require channel-side information since it assigns resources distributed across the transmission bandwidth.

- PFS: Proportional Fair Scheduling is the preferred scheduling mechanism, which basically is a C/I scheduler but with a delay component to address the delay-sensitive traffic.

FLAVIA modularity is obtained via the introduction of reusable services, functions and commands. Modularity is a key aspect of MAC scheduling because the main goal is to demonstrate that heterogeneous scheduling strategies can be dynamically loaded/unloaded and configured at run-time on the top of the WMP.
Because of LTE and 802.16 similarities, modularity can be ported to the LTE technology with minor changes.

Flexibility is a feature inherited by the FLAVIA architecture since it allows creating, enabling, managing, and reconfiguring MAC services by means of well-defined interfaces. As for LTE/802.16 comparison relevant differences are on the PHY layer (different pilot patterns, OFDMA/SC-FDMA, synchronization, etc.).

Virtualization is supported by the FLAVIA architecture since several MAC instances can run in parallel on the same PHY resource. In scheduled systems, virtualization can be obtained by the mean of an appropriate resource scheduling. Both 802.16 and LTE performs user multiplexing, while the former uses flexible arbitrary rectangles in T-F domain, the latter employs LTE stripe-wise allocation in F-Domain. Moreover, the framing TTI is 1ms long in LTE, so the low level API differs from the 802.16 one but maintains the same time requirements.

The scheduler programmability allows a dynamic control on resources by assigning them in time and frequency both in downlink and uplink. During each Transmission Time Interval, resources are allocated to the user equipment by the scheduler. Adaptive and programmable scheduling selects the best multiplexing for UE by considering any combination of: (i) QoS parameters; (ii) measurements, (iii) buffered payloads, (iv) pending retransmission; (v) CQI reports, (vi) UE capabilities, (vii) user equipment sleep cycle, other system parameters.

2.1.4 Intercell-coordination

The FLAVIA architecture has been designed to account for LTE-specific Intercell-coordination features, such as support for automatic configuration of the eNB, automatic configuration of neighbor coordination, load balancing between cells, frequencies and RATs, inter-cell interference mitigation, and coverage and capacity optimizations. These are some of the feature defined for LTE/LTE-A systems starting with 3GPP Release 8 and subsequent releases [3GPP TS 36.902R8, 3GPP TS 36.902R9].

Specifically, the FLAVIA architecture [D2.1.1, D2.2.1, D2.2.2, D3.1.1] specifies the presence of various scheduled-system-oriented services that deal with Intercell-coordination functionalities. Moreover, from a theoretical viewpoint, FLAVIA has proposed novel radio resource management mechanisms that aim to interference mitigation [D5.3]. These mechanisms are suitable for generic scheduled systems, and they can be specifically implemented in LTE, by leveraging the capability of the LTE Evolved Packet Core and by means of the 3GPP Almost Blank Sub-Frame (ABSF) mechanism [4G++].

Introducing Intercell-coordination features in LTE requires the availability of per-user, per-channel, and per-base station statistics in order to allow the network to automatically optimize the cell configuration. Therefore, the goal of Intercell-coordination-oriented services in FLAVIA is to exploit a set of mechanisms for automatic intra-cell and inter-cell network monitoring, in order to enforce the optimization of scheduling parameters. With the above targets, the FLAVIA platform for schedule-based systems has been designed to (*i*) fetch statistics and perform statistical analysis, (*ii*) request channel probing (active measurements), (*iii*) detect the presence of neighbours, (*iv*) detect the noise due to neighbouring cells, and (*v*) use the LTE ECP to coordinate the scheduling tasks of neighbouring base stations. Notwithstanding the complexity of the aforementioned targets, a key feature of FLAVIA Intercell-coordination mechanism is that it incurs a very reduced signalling load between base stations. Indeed, FLAVIA proposes to coordinate base station activities in order to limit the interference caused to any possible user in the system under any possible user scheduling decision taken by the base stations. Therefore, base stations do not need to exchange information with per-user granularity, but rather on a much coarser basis. Another key feature of FLAVIA Intercell-cooperation is that it decouples the problem of mitigating Intercell interference from the problem of optimizing the per-user scheduling at base stations.

As explained in [D5.3], FLAVIA Intercell-cooperation scheme aims at guaranteeing a minimum SINR to every user in the system by allocating in each sub-frame a subset of the available base stations, while minimizing the number of sub-frames needed in order to schedule the complete set of base stations. To achieve this goal, we propose to schedule base station transmissions in each sub-frame so that the SINR is greater than a threshold Th for every user *u* in the network. The problem of minimizing the total number of sub-frames used to schedule once all base stations in the system, for a given minimum SINR (or threshold Th), is formulated using the following notation:

$$SINR_u = \frac{I_b^u}{N_0 + \sum_{j\neq b} I_j^u}\ , \qquad u = 1..U, \qquad u \text{ is connected to base station } b;$$

$$SINR_u \geq \mathrm{Th} \ \Rightarrow \sum_{j=1}^{N} I_j^u \ \leq I_b^u \frac{1+\mathrm{Th}}{\mathrm{Th}} - \ N_0 \triangleq \mathrm{Th}^u\ , \qquad u = 1..U,$$

where I_j^u is the signal received by user *u* from base station *j,* with *b* being the base station of *u*. With this notation, the problem can be stated as follows:

$$\begin{cases} \text{minimize } \ Z = \text{number of sub-frames needed to allocate all base stations once,} \\ \qquad\qquad\qquad \sum_{j=1}^{N} I_j^u\, x_{i,j} \leq \mathrm{Th}^u, \qquad u = 1..U, \\ s.t. \qquad\qquad \sum_{i=1}^{N} x_{i,j} = 1, \qquad j = 1..N, \\ \qquad\qquad x_{i,j} \in \{0,1\}, \qquad i\ = 1..N, \qquad j = 1..N, \end{cases}$$

where $x_{i,j}$ equals 1 if base station *j* is scheduled in sub-frame *i*, and 0 otherwise.
Since the problem formulated above is NP-hard, we design an algorithm to approximate in polynomial time the behaviour of the optimal algorithm. We named such algorithm BASICS [D5.3, SMB13]. Our heuristic is based on a sum-based algorithm that solves k-dimensional vector bin-packing problems by collapsing all problem dimensions (i.e., the interferences to different users) into one unique value. In particular, our heuristic represents a modification of the FFDSum algorithm [CGJ96], in which (*i*) the size of each item to be accommodated changes at each iteration, and (*ii*) items are accommodated into bins in order, beginning with the smallest one.

The ICIC service defined in FLAVIA is mostly responsible for the majority of operations needed to manage the activity of neighbor LTE eNBs, and thus control the inter-cell interference via the control of resource allocation (frequency, time, multiple antennas coordination), interference measurements and reports (intra- and inter-eNB), and power control (e.g., by extending the signaling for uplink power control by taking into consideration indications received by neighbor eNBs). However, as pointed out in [D5.3], the BASICS algorithm can be implemented in FLAVIA by acting on multiple FLAVIA services: MEAS (the measurement service), ICIC, SSON, and SCHE (the MAC scheduler service). First, while BASICS runs in the EPC, it has to be fed with signal levels which are commonly measured by UEs and base stations and are collected at the base station side (through the MEAS service). These measurements shall then be used by the ICIC service to prepare the data to be communicated to the EPC via the inter-entity interface defined in the FLAVIA architecture, namely IAP2. ICIC needs also to keep the SSON service updated with the list of neighbours and potential interferers, which are involved in self-organized networking operations. To this aim, the intra-MAC interface can be used, i.e., IAP5. SSON is responsible for managing the communication with the EPC and to pass to the SCHE service the base station decisions taken by BASICS. Such decisions are interpreted by the base stations and enforced as ABSF periodic patters. Therefore, base stations that are not scheduled by the BASICS algorithm in a given frame will transmit according to the 3GPP ABSF patterns (i.e., they *almost blank* that particular subframe).

Notably, Intercell-coordination (and not just the BASICS algorithm) in FLAVIA is assisted by SON operations. In particular, the SSON service defined in FLAVIA can be used to automatically and synchronously monitoring multiple LTE cells with the aim to self-optimize PHY/MAC/handover parameters used by LTE eNBs. Monitoring includes collecting radio and traffic statistics, neighbor statistics and relations, but also active channel probing and neighbor search. Optimization covers the selection of parameters to be used for antennas and transmission powers, e.g., the antenna tilt to regulate the coverage and capacity of a cell. Optimization also covers the selection of frequencies to be used, and the inter-cell scheduling of resource blocks to reduce inter-cell interference.

2.1.5 Admission Control

The Radio Admission Control is one of the Radio Resource Management (RRM) functions hosted in the eNB. As specified in 3GPP Technical Specification 36.300, functions for Radio Resource Management include: Radio Bearer Control, Radio Admission Control, Connection Mobility Control, Dynamic allocation of resources to UEs in both uplink and downlink (scheduling).

As described in [3GPP TS 36.300] the task of Radio Admission Control (RAC) is to admit or reject the establishment requests for new radio bearers. In order to do this, RAC takes into account the overall resource situation in E-UTRAN, the QoS requirements, the priority levels and the provided QoS of in-progress sessions and the QoS requirement of the new radio bearer request. RAC has two main goals:

- To ensure high radio resource utilization (by accepting radio bearer requests as long as radio resources available)
- At the same time to ensure proper QoS for in-progress sessions (by rejecting radio bearer requests when they cannot be accommodated).

Figure 26 depicts a successful Radio Resource Control (RRC) connection establishment as described in [3GPP TS 36.331]. In Figure 27 we can see a situation in which the radio admission control entity has rejected the RRC connection request.

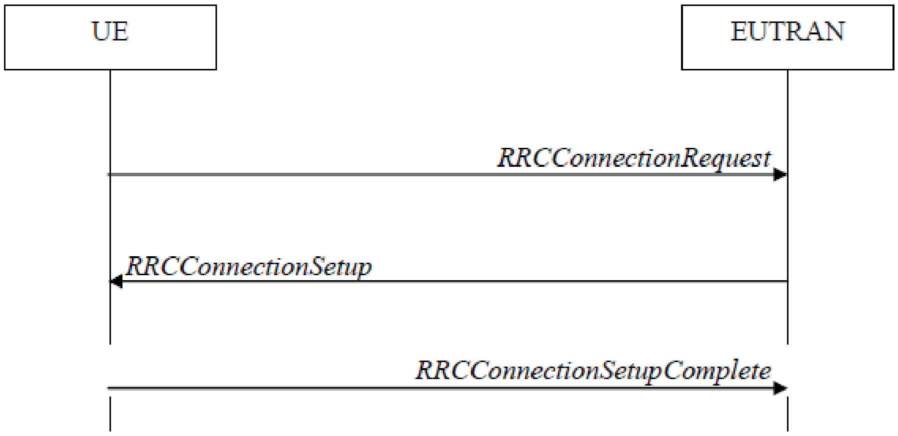


Figure 26 RRC connection establishment, successful [3GPP TS 36.331]

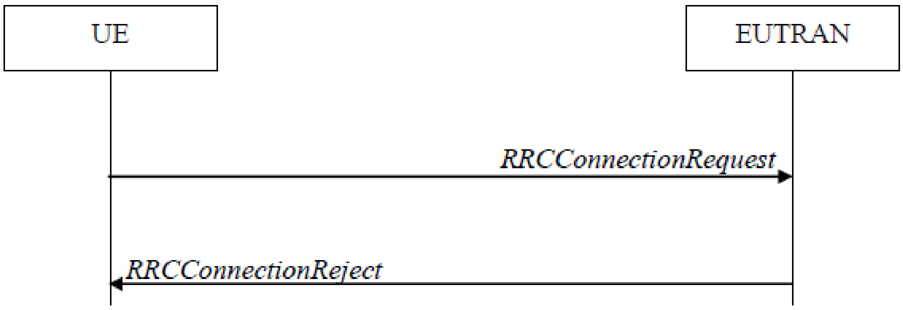


Figure 27 RRC connection establishment, network reject [3GPP TS 36.331]

Admission Control may be performed by the target eNB dependent on the received E-RAB QoS information. The target eNB configures the required resources according to the received E-RAB QoS information.

The admission control determines how radio resources are allocated to "Guaranteed Bit Rate" (GBR) bearers activated by the UE's. The admission control procedure admits a GBR radio bearer if and only if it is possible to allocate requested resources for that bearer for both the Uplink and the Downlink. Admission control process can be improved for GBR bearers by implementing a function that monitors traffic activity on that bearer. With this feature enabled on an eNB, the resources requested for a bearer will match closely to the actual traffic that the bearer carries irrespective of the configured traffic contract. To customize the admission control process the traffic usage related to a particular bearer is monitored constantly and as soon as there is a slack in this traffic at some particular point in time then the admission control process does some math and activates another bearer if resources are available.

Queue selection of non-GBR bearers during scheduling is based on equal capacity sharing basis. The scheduler evenly allocates all its available resources within a single frame to all equal priority bearers carrying traffic. For each allocation, control information is created in PDCCH.

In deliverable D3.1.1 Section 3.27 we specified the access control function interfaces and primitives defined in FLAVIA architecture for IEEE 802.16. After a revision of the interfaces and primitives we can conclude that the defined interfaces and primitives could be applied for basic admission control in the LTE case.

As an example Primitive *LADA_IAP5_estimated_MCS_REQ/REP* would be used for requesting the regular channel estimation measurements from UEs. Primitive *QOSS_IAP5_QoS_attributes_REQ/REP* would be used to obtain the QoS information of the existing connections which is received by the eNB in the E-RAB QoS information. Primitive *ADCO_IAP6_connection_conf_REQ/REP* would be used to request admission control process initiation when upper layers request establishment of an RRC connection while the UE is in RRC_IDLE state.

In order to obtain full LTE support we would have to extend some of the primitives, especially in the UE measurements case to adapt to the specific metrics defined in the 3GPP specifications.

2.2 FLAVIA LTE Concepts - Market Forecast

The architecture developed and promoted by the FLAVIA project defines a networking paradigm change enabling unprecedented network equipment functionality flexibility and virtualization capabilities. Among the different use cases considered, network infrastructure sharing is a major example where such capabilities are expected to be needed. The wide acceptance of the infrastructure sharing concept in the marketplace though depends on the view of the different players in the ecosystem regarding the pros and cons for their own business development. In the following we summarize some of the main findings reported in an industry survey network sharing market research [NS-Industry Survey 2013].

This market research summarizes the feedback of about 2000 telecom.com readers where around 600 of them work at operators around the world and 260 individual operating companies were represented. According to the survey results, about 60% of respondents agreed that networks sharing is *essential* to the profitability of LTE deployments (~18% strongly). This is a very strong message to the vendors industry since it means that a major trend is moving towards this direction. Morover, as hown in the next figure, about 36% of respondents believe that single network mobile markets, in which operators compete at the service layer only, are commercially viable.

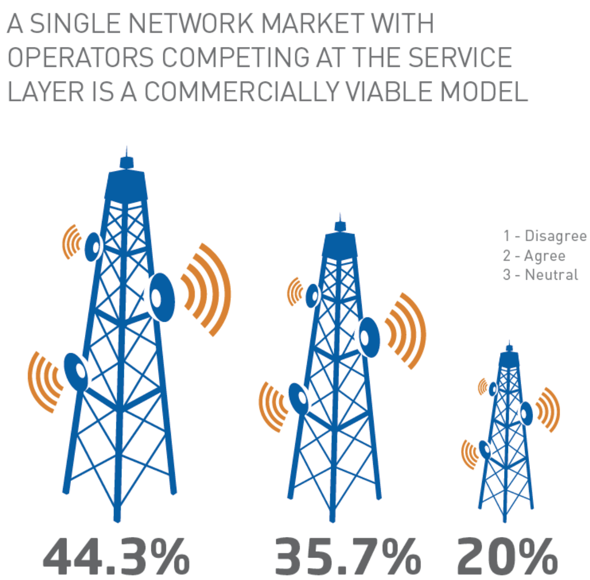


Figure 28. Single network as commercially viable model. Source: [NS-Industry Survey 2013].

Further insights were provided by the results shown in the next figure where figures regarding the number of separately owned operators estimated as required for a country are provided. Two thirds of respondents to the survey believe that mobile operators are too numerous, with about 65% saying that further consolidation in the operator community is necessary. Regarding the number of operators a market will be able to support in two years' time, about 40% considered three as a reasonable number, 29% felt their market could sustain four operators, while 17% asserted that there were pickings rich enough for five or more players.

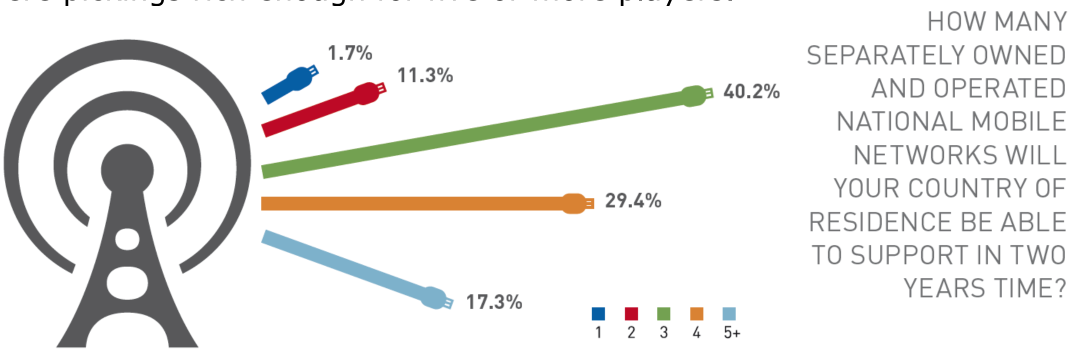


Figure 29. Number of separately owned national mobile networks per country. Source: [NS-Industry Survey 2013].

Based on these results, we can conclude that the research performed within the FLAVIA project is strongly aligned with the forecasted market needs specially in the LTE area.

3 Detailed List of Project Dissemination Output

3.1 Publications

Journal Publications

Title: "WMPS: A Positioning System for Localizing Legacy 802.11 Devices"

Journal: IEEE Transactions on Smart Processing and Computing Journal

FLAVIA partners: CNIT

Title: Radio Access Network Virtualization for Future Mobile Carrier Networks

Journal: IEEE Communications Magazine, July 2013

FLAVIA partners: NEC

Title: Latest Trends in Telecommunication Standards

Journal: ACM Computer Communications Review, April 2013

FLAVIA partners: NEC

Title: Mitigating Collisions through Power-Hopping to Improve 802.11 Performance

Journal: (accepted) Elsevier Pervasive and Mobile Computing

FLAVIA partners: NUIM

Title: Cross-Layer Metrics for Reliable Routing in Wireless Mesh Networks

Journal: (accepted, available online on IEEE XPLORE) IEEE/ACM Transactions on Networking

FLAVIA partners: MobiMESH

Title: A Survey on Opportunistic Scheduling in Wireless Communications

Journal: (accepted, available online on IEEE XPLORE) IEEE Communications Surveys and Tutorials

FLAVIA partners: IMDEA, UC3M

Title: A Game Theoretic Approach to Distributed Opportunistic Scheduling

Journal: (accepted) IEEE/ACM Transactions on Networking

FLAVIA partners: IMDEA, UC3M

Title: Control Theoretic Optimization of 802.11 WLANs: Implementation and Experimental Evaluation

Journal: Computer Networks (Elsevier), Volume 57, Issue 1, 16 January 2013, Pages 258-272, ISSN 1389-1286, 10.1016/j.comnet.2012.09.010.

FLAVIA partners: IMDEA, UC3M, NUIM

Title: Providing Throughput and Fairness Guarantees in Virtualized WLANs through Control Theory

Magazine or Journal: Mobile Networks and Applications, Springer, vol. 17, no. 4, pp. 435-446

FLAVIA partners: AGH, IMDEA, NUIM.

Title: Greening Wireless Communications: Status and Future Directions

Magazine or Journal:(accepted) Elsevier Computer Communications

FLAVIA partners: IMDEA, NUIM.

Title: What's New for QoS in IEEE 802.11?

Magazine or Journal:(accepted) IEEE Network Magazine

FLAVIA partners: AGH, IITP, CNIT.

Title: Analytical model of interaction between contention-based and deterministic channel access methods in Wi-Fi Mesh networks

Magazine or Journal: (accepted) Automation and Remote Control, Vol. 74, No. 10, 2013.

FLAVIA partners: IITP

Title: Groupcast routing with the possibility to choose a channel transmission method

Magazine or Journal: (accepted) Automation and Remote Control, Vol. 74, No. 10, 2013.

FLAVIA partners: IITP

Title: A Survey of Medium Access Mechanisms for Providing QoS in Ad-Hoc Networks

Magazine or Journal: IEEE Communications Surveys and Tutorials, 10.1109/SURV.2012.060912.00004, published online 27 June 2012

FLAVIA partners: AGH, CNIT

Title: Analytical Study of the Quality of Links Established by Neighborhood Discovery Protocol

Magazine or Journal: Springer Journal of Communications Technology and Electronics, Vol. 57, No 12, P. 1314-1321, 2012.

FLAVIA partners: IITP.

Title: *A method to estimate efficiency of the connection control mechanisms in wireless self-organizing networks*

Magazine or Journal: *Automation and Remote Control, Volume 73, Number 5 (2012)*

FLAVIA partners: *IITP*

Title: Designing Energy Efficient Access Points with Wi-Fi Direct

Magazine or Journal: Elsevier Computer Networks Journal (CN), Volume 55, Issue 13, September 2011

FLAVIA partners: NEC

Title: Throughput and energy-aware routing for 802.11 based Mesh Networks

Magazine or Journal:(accepted) Elsevier Computer Communications

FLAVIA partners: IMDEA

Title: Analysis of power saving with continuous connectivity

Magazine or Journal: International Journal of Computer and Telecommunications Networking (Computer Networks), Special Issue on Green Communication Networks, Volume 56, Issue 10, 5 July 2012, Pages 2481–2493.

FLAVIA partners: IMDEA

Title: Balancing Energy Efficiency and Throughput Fairness in IEEE 802.11 WLANs

Magazine or Journal: (accepted) Elsevier Pervasive and Mobile Computing

FLAVIA partners: IMDEA

Title: Analysis of power saving and its impact on web traffic in cellular networks with continuous connectivity

Magazine or Journal: (accepted) Elsevier Pervasive and Mobile Computing

FLAVIA partners: IMDEA

Title: Correlation of Wireless Link Quality: A Distributed Approach for Computing the Reception Correlation

Magazine or Journal: IEEE Communications Letters

FLAVIA partners: MOBI

Title: MAC Design for WiFi Infrastructure Networks: a game-theoretic approach

Magazine or Journal: IEEE Transactions on Wireless Communications

FLAVIA partners: CNIT

Title: Analytical model of IEEE 802.11s MCCA based streaming in the presence of noise

Magazine or Journal: ACM SIGMETRICS Performance Evaluation Review 2011

FLAVIA partners: IITP

Title: Analytical Study of QoS Oriented Multicast in Wireless Networks

Magazine or Journal: EURASIP Journal on Wireless Communications and Networking, Vol. 11. Article ID 307507. 2011

FLAVIA partners: IITP

Title: Decentralised learning MACs for collision-free access in WLANs

Magazine or Journal: Springer Wireless Networks, 2012

FLAVIA partners: NUIM

Title: Coded Unicast Downstream Traffic in a Wireless Network: Analysis and WiFi Implementation
Journal: EURASIP Journal on Advances in Signal Processing 2013

FLAVIA partners: BGU

Conference Publications

Title: "Wireless Card Virtualization: From Virtual NICs to Virtual MAC Machines." (2012).
FLAVIA partners: CNIT, IMDEA, TID
Event: Future Networks and Mobile Summit, Berlin 2012

Title: "WIDAR: bistatic WI-fi Detection And Ranging for off-the-shelf devices"
FLAVIA partners: CNIT
Event: To appear in proceeding of WoWMoM 2013, Madrid.

Title: Deploying Virtual MAC Protocols Over a Shared Access Infrastructure Using MAClets.",
FLAVIA partners: CNIT
Event: INFOCOM 2013

Title: "A Control Architecture for Wireless MAC Processor Networking"
FLAVIA partners: CNIT
Event: Future Network and MobileSummit 2013 Conference Proceedings, Lisbon 2013.

Title: "Breaking Layer 2: A New Architecture for Programmable Wireless Interfaces"
FLAVIA partners: CNIT, IITP
Event: ICTC 2012, South Korea

Title: "MAClets: Active MAC Protocols over hard-coded devices".
FLAVIA partners: CNIT
Event: ACM CoNEXT 2012, Nice, France.

Title: "Wireless Card Virtualization: From Virtual NICs to Virtual MAC Machines"
FLAVIA partners: CNIT, TID, IMDEA
Event: FUNEMS 2012, Berlin, July 2012.

Title: Coded Unicast Downstream Traffic in a Wireless Network: Analysis and WiFi Implementation
Conference: IEEE 27-th Convention of Electrical and Electronics Engineers in Israel 2012, Eilat, Israel
FLAVIA partners: BGU

Title: Capacity, Scheduling and Multi-User Diversity in MIMO channels
Conference: Information Theory and Applications, San-Diego, February 2013
FLAVIA partners: BGU

Title: Distributed Scheduling for Achieving Multi- User Diversity
Conference: Information Theory and Applications, San-Diego, February 2012
FLAVIA partners: BGU

Title: MAC Capacity Under Distributed Scheduling of Multiple Users and Linear Decorrelation
Conference: Israeli Networking Day, Tel Aviv, Israel, April 2013
FLAVIA partners: BGU

Title: Opportunistic Scheduling in Heterogeneous Networks: Distributed Algorithms and System Capacity
Conference: Israeli Networking Day, Tel Aviv, April 2012
FLAVIA partners: BGU

Title: The Risks of WiFi Flexibility: Enabling and Detecting Cheating

Conference: Future Network and MobileSummit 2013

FLAVIA partners: AGH, CNIT

Title: Making IEEE 802.11 Wireless Access Programmable

Conference: Future Network and MobileSummit 2013

FLAVIA partners: IITP, CNIT, UC3M

Title: Detecting Transmission Power Misbehaviour in Wi-Fi Networks

Conference: International Workshop on Wireless Access Flexibility (WiFlex)

FLAVIA partners: AGH

Title: 802.11 Buffers: When Bigger is Not Better?

Conference: International Workshop on Wireless Access Flexibility (WiFlex)

FLAVIA partners: NUIM

Title: Dynamic Resource Allocation for MCCA-Based Streaming in Wi-Fi Mesh Networks

Conference: International Workshop on Wireless Access Flexibility (WiFlex)

FLAVIA partners: IITP

Title: Practical Node Policing in 802.11 WLANs (demo)

Conference: 14th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2013), Madrid, Spain

FLAVIA partners: NUIM

Title: Mobile Access of Wide-Spectrum Networks: Design, Deployment and Experimental Evaluation

Conference: IEEE International Conference on Computer Communications (INFOCOM), Turin, Italy, April 2013

FLAVIA partners: NUIM

Title: A Bandwidth Trading Marketplace for Mobile Data Offloading

Conference: IEEE International Conference on Computer Communications (INFOCOM Mini conference), Turin, Italy, April 2013

FLAVIA partners: MobiMESH

Title: An Innovative Rate Adaptation Algorithm for Multicast Transmissions in Wireless LANs

Conference: 77th IEEE Vehicular Technology Conference: VTC2013-Spring 2-5 June 2013, Dresden, Germany

FLAVIA partners: CNIT, MobiMESH

Title: Energy Efficient Opportunistic Uplink Packet Forwarding in Hybrid Wireless Networks

Conference: ACM e-Energy 2013, Berkeley, CA, USA.

FLAVIA partners: IMDEA, UC3M

Title: BASICS: Scheduling Base Stations to Mitigate Interferences in Cellular Networks

Conference: 14th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2013), Madrid, Spain

FLAVIA partners: IMDEA, UC3M

Title: A novel Intercell Coordinated Scheduling approach using Application Reservation Information

Conference: WCNC 2013, Shanghai, China

FLAVIA partners: IMDEA, NEC

Title: Energy consumption anatomy of 802.11 devices and its implication on modeling and design

Conference: ACM CoNEXT 2012 – December 10-13 2012, Nice, France

FLAVIA partners: IMDEA, CNIT

Title: Analytical Study of Neighborhood Discovery and Link Management in OLSR

Conference: IFIP Wireless Days 2012

FLAVIA partners: IITP

Title: Breaking Layer 2: A New Architecture for Programmable Wireless Interfaces

Conference: IEEE Int. Conf. on Information and Communication Technology Convergence (ICTC 2012), Jeju Island, Korea, 2012.

FLAVIA partners: CNIT, IITP

Title: Analytical Study of Link Management in IEEE 802.11s Mesh Networks

Conference: International Symposium on Wireless Communication Systems (ISWCS) 2012

FLAVIA partners: IITP

Title: 802.11ec: Collision Avoidance without Control Messages

Conference: ACM MobiCom 2012

FLAVIA partners: BGU

Title: Asymmetric Uplink-Downlink Assignment for Energy-Efficient Mobile Communication Systems

Conference: IEEE Vehicular Technology Conference 2012

FLAVIA partners: NEC

Title: Achievable Net-Rates in Multi-User OFDMA with Partial CSI and Finite Channel Coherence

Magazine or Journal:(accepted) IEEE Vehicular technology Conference Fall 2012, Sep, 2012

FLAVIA partners: NEC

Title: Mathematical model of MCCA-based streaming process in mesh networks in the presence of noise

Conference: WCNC 2012

FLAVIA partners: IITP

Title: On designing next generation MAC for cellular networks using the FLAVIA paradigm

Conference: ICT Future Network & Mobile Summit, 2012

FLAVIA partners: IMDEA, BGU, NEC, Alvarion

Title: Exploiting the Capture Effect to Improve WLAN Throughput

Conference:IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2012

FLAVIA partners: NUIM

Title: A Game-Theoretic Approach to EDCA Remapping Attacks

Conference: (accepted) 8th International Conference on Wireless Communications, Networking and Mobile Computing (WiCom), 2012

FLAVIA partners: AGH

Title: Wireless Card Virtualization: From Virtual NICs to Virtual MAC Machines

Conference: ICT Future Network & Mobile Summit, 2012

FLAVIA partners: Telefonica, CNIT

Title: A modular, flexible and virtualizable framework for IEEE 802.11

Conference: ICT Future Network & Mobile Summit, 2012

FLAVIA partners: IMDEA, CNIT, MOBI, AGH, NEC, NUIM, TID

Title: Wireless MAC Processors: Programming MAC Protocols on Commodity Hardware

Conference: IEEE INFOCOM 2012

FLAVIA partners: CNIT

Title: Distributed Opportunistic Scheduling: A Control Theoretic Approach

Conference: IEEE INFOCOM 2012

FLAVIA partners: IMDEA

Title: VoIPiggy: Implementation and evaluation of a mechanism to boost voice capacity in 802.11 WLANs

Conference: IEEE INFOCOM 2012

FLAVIA partners: IMDEA, CNIT

Title: Interference, even with MCCA channel access method in IEEE 802.11s mesh networks

Conference: IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2011)

FLAVIA partners: IITP

Title: Flexibility of Routing Framework Architecture in IEEE 802.11s Mesh Networks

Conference: IEEE International Conference on Mobile Ad-hoc and Sensor Systems (IEEE MASS 2011)

FLAVIA partners: IITP

Title: *Insomnia in the Access or How to Curb Access Network Related Energy Consumption*

Conference: ACM SIGCOMM 2011

FLAVIA partners: TID

Title: *On the Flexibility of the IEEE 802.11 Technology: Challenges and Directions*

Conference: ICT Future Network & Mobile Summit, 2011

FLAVIA partners: CNIT

Title: *FLAVIA: Towards a Generic MAC for 4G Mobile Cellular Networks*

Conference: ICT Future Network & Mobile Summit, 2011

FLAVIA partners: ALV, BGU, IMD, NEC

Title: *Energy-efficient fair channel access for IEEE 802.11 WLANs*

Conference: IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2011

FLAVIA partners: IMD

Title: *Coloring-based resource allocations in ad-hoc wireless networks*

Conference: MedHoc, 2011

FLAVIA partners: CNIT

Title: *Maximizing network capacity in an heterogeneous macro-micro cellular scenario*

Conference: IEEE ISCC, 2011

FLAVIA partners: CNIT

Title: A framework for Packet-Droppers Mitigation in OLSR Wireless Community Networks

Conference: IEEE ICC, 2011

FLAVIA partners: CNIT

Title: Traffic-Centric Modellingby IEEE 802.11 DCF Example

Conference: ASMTA 2011

FLAVIA partners: CNIT

Title: Power save analysis of cellular networks with continuous connectivity

Conference: IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2011

FLAVIA partners: IMD

Title: Resource Efficiency of Traffic-Centric Model for Complex LTE systems

Conference: Fourth International Conference on Computational Intelligence, Modelling and Simulation (CIMSiM 2012)

FLAVIA partners: CNIT

Title: Capacity of Distributed Opportunistic Scheduling in Heterogeneous Networks
Conference: 50th Annual Allerton Conference on Communication, Control, and Computing (Allerton 2012)

FLAVIA partners: BGU

3.2 Presentations

Title: Network Coded Gossip with Correlated Data (and a little bit on distributed scheduling
Event: This talk was given at Technion (April 2012), Bar Ilan (May 2012); MIT (September 2012), Boston University (September 2012)
FLAVIA partner: BGU

Title: Network Coding with Side Information: from Gossip Schemes to Markov Decision Processes
Event: The Hebrew University of Jerusalem, June, 2013
FLAVIA partner: BGU

Title: Radio Access Network Virtualization and Sharing for Future Mobile Carrier Networks

Event: RAN evolution to the Cloud Workshop – EU FP7 Mobile Cloud Networking IP Project – June 2013

FLAVIA partner: NEC

Title: Harnessing Spectral Diversity for Mobile Access in Unlicensed Wireless Networks

Event: Seminar – Technical University of Darmstadt – 24 April 2013
FLAVIA partner: NUIM

Title: FP7 FLAVIA: 3GPP RAN Sharing Enhancements

Event: EU FP7 Concertation Meeting – RAS Cluster – February 2013
FLAVIA partner: NEC

Title: Maclets

Event: Seminar - Petit Amphi, campus Telecom Bretagne, Rennes – 7 November 2012
FLAVIA partner: CNIT

Title: Wireless MAC Processors: Programming and Running MAClets over Hard-Coded Devices

Event: Presentation of the Wireless MAC Processors at University of Padova - October 2012
FLAVIA partner: CNIT

Title: Wireless MAC Processors: Programming MAC on commodity hardare

Event: Seoul National University invited talk about the FLAVIA project - Seoul, 18 October 2012
FLAVIA partner: CNIT

Title: FLAVIA: Wireless access programmability: new architectural insights and proof-of-concept validation on commodity cards

Event: Future Networks 9th FP7 Concertation Future Internet Cluster Meeting (2012), Workshop: Novel Networking architectures - The Impact of Software Defined Networking, OpenFlow and new Flow Switching Technologies

FLAVIA partner: CNIT

Title: Tutorial on Wireless MAC processors (FLAVIA Project)

Event: Future Networks 9th FP7 Concertation Radio Access and Spectrum Cluster Meeting (13 February 2012, Brussels)

FLAVIA partner: CNIT

Title: Wireless Card Virtualization: From Virtual NICs to Virtual MAC Machines

Event: ICT Future Network & Mobile Summit, 2012

FLAVIA partner: CNIT

Title: FLAVIA: Fostering Cognitive Radio Deployment: A New Architecture for Real-time Wireless Stack Reconfiguration

Event: ICT Future Network & Mobile Summit, 2012, Workshop 2b: Cognitive Radio/Cognitive Networks

FLAVIA partner: CNIT

Title: Wireless Processor - Technology Overview and Demonstration

Event: ICT Future Network & Mobile Summit, 2012, Workshop 10e: Fostering Programmability of Wireless Networks II

FLAVIA partner: CNIT & NEC

Title: On designing next generation MAC for cellular networks using the FLAVIA paradigm

Event: ICT Future Network & Mobile Summit, 2012

FLAVIA partner: IMDEA

Title: Let Me Grab Your App: A Preliminary Proof-of-Concept Design of Opportunistic Content Augmentation

Event: IEEE International Conference on Communication 2012

FLAVIA partners: CNIT

Title: From wireless cards to wireless processors

Event: IEEE IFIP Annual Mediterranean Ad Hoc Networking Workshop (MedHoc 2011)

FLAVIA partners: CNIT

Title: How to Deal with a Thousand Nodes: M2M Communication over Cellular Networks

Event: Fachtagung des ITG Fachausschusses 5.2 Kommunikationsnetze und –systeme

FLAVIA partners: NEC

Title: Research in theory and practice

Event: IMDEA Networks Open House

FLAVIA partners: IMD

Title: Energy efficiency in Wireless Access Networks

Event: IMDEA Networks Open House

FLAVIA partners: IMD

Title: VoIPiggy: Implementation and evaluation of a mechanism to boost voice capacity in 802.11 WLANs

Event: IMDEA Networks Open House

FLAVIA partners: IMD

Title: The validity of IEEE 802.11 MAC modelling hypotheses

Event: The International Workshop on Multiple Access Communications (MACOM), Sept. 2010

FLAVIA partners: NUIM

Title: Playing with Standards: the IEEE802.11 case

Event: Joint discussion with the University of Aachen

FLAVIA partners: CNIT

Title: Adding flexibility, modularity and virtualization capabilities to the wireless world: the FLAVIA project approach

Event: Joint discussion with the University of Aachen

FLAVIA partners: CNIT

Title: Exploiting the Capture Effect to Improve WLAN Throughput & Practical Policing in WiFi

Event: NUI Maynooth President's visit @ Hamilton Institute

FLAVIA partners: NUIM

Title: Understanding 802.11 Packet Buffers

Event: Royal Irish Academy Research Colloquium

FLAVIA partners: NUIM

3.3 Workshops, Tutorial, Panels and Special Issues

Workshops

Workshop: 5^{th} International Workshop on Multiple Access Communications (MACOM 2012)

FLAVIA partners: NUIM

Workshop: Fostering Programmability of Wireless Networks

Associated conference: ICT Future Network & Mobile Summit, 2012

FLAVIA partners: NEC, CNIT

Workshop: International Workshop on Wireless Access Flexibility (WiFlex 2013)

Associated conference:

FLAVIA partners:IITP, CNIT

Workshop: [Workshop on Wireless Network Testbeds, Experimental evaluation and Characterization(WINTECH)]

Associated conference: ACM Mobicom Conference 2011

FLAVIA partners: CNIT, IMD,NEC,TID

Workshop: [Fifth IEEE International Workshop onEnabling Technologies and Standards forWireless Mesh Networking (MeshTech'11)]

Associated conference: IEEE MASS 2011

FLAVIA partners: IMD, CNIT, NEC, NUIM, TID

Tutorial

Workshop: [Fostering Programmability of Wireless Networks]

Associated conference: ACM SIGCOMM 2012

FLAVIA partners: NEC, CNIT

Panels Organization

Panel: [Disruptive Technologies for Future Wireless Networks]

Conference: International Workshop on Computer-Aided Modeling Analysis and Design of Communication Links and Networks (CAMAD)

FLAVIA partners: NEC

Panel: [Future Wireless Networks]

Conference: IEEE Wireless Communications and Networking Conference 2011

(WCNC)

FLAVIA partners: NEC, CNIT

Journals or Magazine Special Issues Organization

Special Issue: Wireless Green Communications and Networking

Journal or Magazine: Elsevier Computer Communications Journal

FLAVIA partners: NEC

Informative online notes

Media: Madri+d online journal

Title: FLAVIA: a unified architecture for future wireless devices

FLAVIA partners: IMDEA

3.4 Standardization

3GPP

Working Group: System Architecture Working Group 1 (SA1)

Contribution: Technical Report on RAN Sharing Enhancements Study Item

FLAVIA partners: NEC

Working Group: RAN WG3

Contribution: RAN Sharing Enhancements Discussion

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: RAN Sharing Enhancements Technical Report 22.852 v01

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: RAN Sharing Enhancements Technical Report 22.852 v02

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: Definitions and Abbreviations for TR 22.852

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: Use Cases for RAN Sharing

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: Use Cases for RAN Sharing

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: Use Cases for RAN Sharing

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: RSE Use Cases - Monitoring

FLAVIA partners: NEC

Working Group: System Architecture Working Group 1 (SA1)

Contribution: RSE - what constitutes a shared RAN

FLAVIA partners: NEC

ETSI

Working Group: Automatic Network Engineering for the Self-managing Future Internet (AFI) Industry Specification Groups (ISG)

FLAVIA partners: AGH

Working Group: Automatic Network Engineering for the Self-managing Future Internet (AFI) Industry Specification Groups (ISG)

Contribution: Wi-Fi Network Robustness Use Case (requires ETSI login)

FLAVIA partners: AGH

Working Group: Automatic Network Engineering for the Self-managing Future Internet (AFI) Industry Specification Groups (ISG)

Contribution: Updated Wi-Fi Network Robustness Use Case (requires ETSI login) Accepted for the ETSI Technical Specification "Autonomic network engineering for the self-managing Future Internet (AFI): Scenarios, Use Cases and Requirements for Autonomic/Self-Managing Future Internet" (to be released in 2013)

FLAVIA partners: AGH

IEEE 802.16

Working Group: Machine-to-Machine Task Group (802.16p)

Contribution: Group-based Allocation of Random Access Resources (C802.16p-11/0034r1)

FLAVIA partners: NEC

Working Group: Machine-to-Machine Task Group (802.16p); Rapporteur Group on Large Number of Devices

Contribution: Random Access Resource Allocation for Large Number of Devices (C802.16p-rg-11/0028r1; password required)

FLAVIA partners: NEC

Working Group: Machine-to-Machine Task Group (802.16p)

Contribution: Optimized schemes of network re-entry for M2M in 16m (C802.16p-11/0161r4)

FLAVIA partners: NEC

Working Group: Machine-to-Machine Task Group (802.16p)

Contribution: Optimized schemes of network re-entry for M2M in 16e (IEEE C802.16p-11/0162r3)

FLAVIA partners: NEC

IEEE 802.11

Working Group: Wireless Next Generation (WNG) Standing Committee (SC)

Contribution: Parameterized QoS for 802.11s mesh networks

FLAVIA partners: IITP

Working Group: Wireless next Generation (WNG) Standing Committee (SC)

Contribution: Flexibility on Channel Access Allocations

FLAVIA partners: IMD, CNIT

Working Group: Robust streaming of Audio Video Transport Streams (TGaa)

Contribution: MRG IFS Correction

FLAVIA partners: IITP

Working Group: Robust streaming of Audio Video Transport Streams (TGaa)

Contribution: GCR for mesh

FLAVIA partners: IITP

Working Group: Mesh (TGs)

Contribution: Audio and video support by MCCA

FLAVIA partners: IITP

Working Group: Mesh (TGs)

Contribution: Access during an MCCAOP by mesh STAs that are not the MCCAOP owner

FLAVIA partners: IITP

Working Group: Robust streaming of Audio Video Transport Streams (TGaa)

Contribution: MRG for mesh

FLAVIA partners: IITP

3.5 FLAVIA Project Enlargement

One of the goals of enlarging FLAVIA by introducing a new partner (AGH) in the second year of the project was reinforcing cooperation between partners. This goal has been achieved by a new bilateral cooperation project between AGH and CNIT entitled "ADvanced wifi networks for HOme Customized applications (ADHOC)" (2013-2015). It is being financed by the Italian Ministry of Foreign Affairs and Polish Ministry of Science and Higher Education within the CANALETTO Programme. The goal of the programme is to facilitate already established Italian and Polish research cooperation offering finances for the exchange of persons working in the research teams.

The proposed ADHOC project deals with the analysis of solutions for adapting home ad-hoc networks to different application requirements and environment conditions. This research project can be considered as a niche-scenario extension of FLAVIA. Since the FLAVIA project proposed a new architecture of wireless cards supporting flexible and virtual functionalities, the idea is to exploit this adaptability of emerging wireless cards in home network scenarios.

4 Annexes

4.1 The wireless MAC processor exploitation

Exhibitions

In addition to the Wireless MAC Processor release on the FLAVIA project website, an additional webpage has been realized on the UNIPA (Università di Palermo, member of CNIT) webpage. The WMP website www.wmp.tti.unipa.it has been renewed; new content has been added. The wmp websites points to a github repository where Wireless MAC Processor tools can be downloaded. Posters presented in Barcelona were added on the website and some Google analytics statistics are shown in the following pictures and tables, demonstrating that the interest in the activity is relevant. The Wireless MAC Processor was presented at the WiFi World Summit Exhibition, an event held in Barcelona. Two posters (one technical and one more marketing oriented) were presented. During the event some companies (also among the exhibitors) were interested to our solution, among them XIRRUS, ZTE, and a representative of the WiFi Alliance. It is available also a video:
http://www.bnettv.com/wifi-world-summit-in-barcelona-spain-2012/?channelId=244a36170379450492901 2066ae7c301&channelListId&mediaId=b8ec0f3a2733436f930aa3dd43566bb7

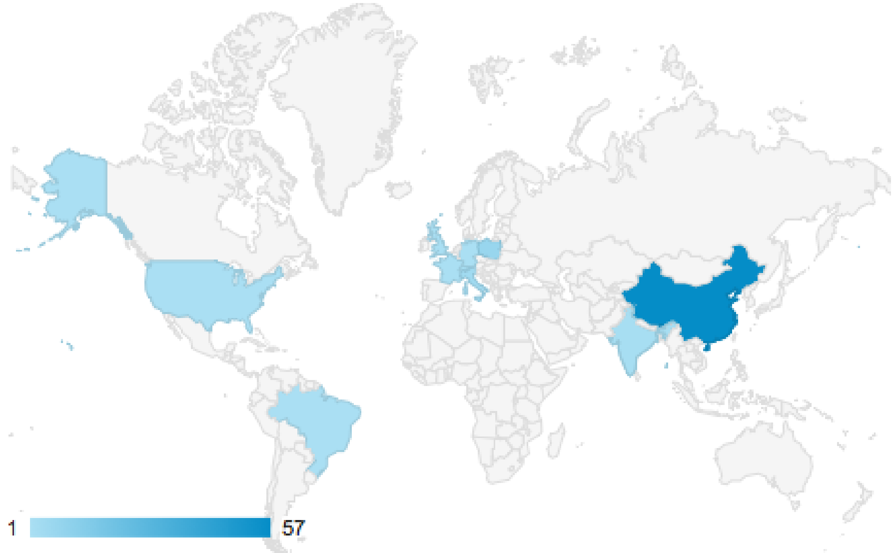
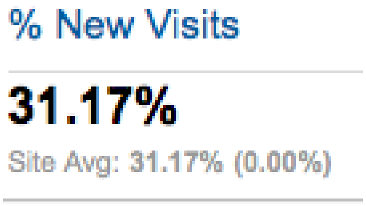


Figure 30 Visits per country (late 2013)

Figure 31 Visits per country (from the website publication)



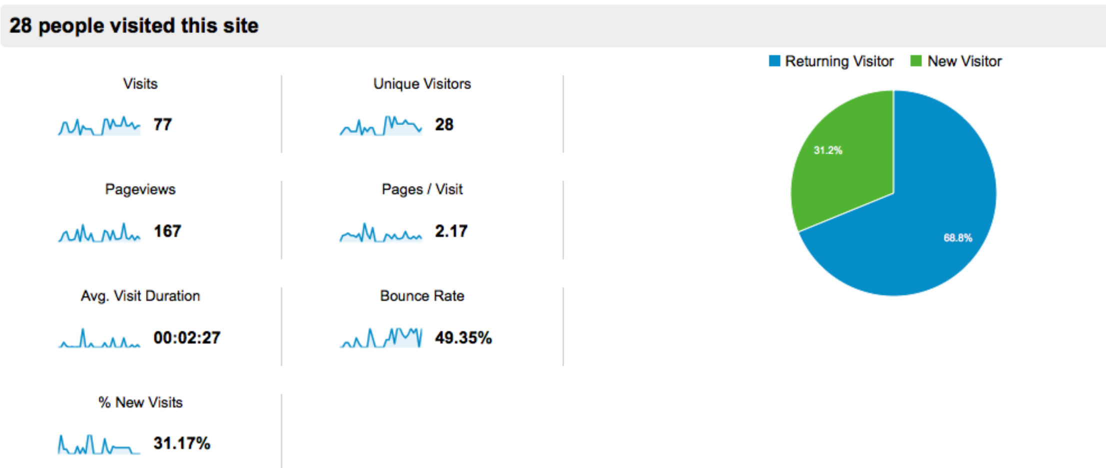


Figure 32 WMP website stats overview

Current Country Totals
From 20 Jun 2012 to 4 May 2013

Italy (IT)	70
Sicilia	55
Lazio	5
Toscana	4
Liguria	3
Lombardia	2
Umbria	1
Spain (ES)	29
China (CN)	25
Germany (DE)	13
Switzerland (CH)	11
United States (US)	9
Poland (PL)	7
Korea, Republic of (KR)	7
Belgium (BE)	5
Brazil (BR)	3
France (FR)	3
Europe (EU)	2
Finland (FI)	1
Ireland (IE)	1
United Kingdom (GB)	1
Russian Federation (RU)	1
Canada (CA)	1
Malaysia (MY)	1
Taiwan (TW)	1
Japan (JP)	1

Figure 33 WMP website stats overview (per country)

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