Specific Targeted Research Project

FLAVIA
FLexible Architecture for Virtualizable wireless future Internet Access

Deliverable Report

D 2.1.2 Revision of Report on Scenarios, Services and Requirements

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Authors	Ilenia Tinnirello, Pierluigi Gallo (CNIT), Xavier Perez-Costa (NEC), Pablo Serrano, Pablo Salvador (IMDEA), Antonio Capone, Alberto Pollastro, Domenico Schillaci (MOBIMESH), Artem Krasilov, Andrey Lyakhov (IITP), Katarzyna Kosek-Szott, Marek Natkaniec, Szymon Szott (AGH), David Malone, Paulo Patras (NUIM)
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STATEMENT OF ORIGINALITY

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Executive summary

This report aims to support the *validation* and the *revision* of the initial FLAVIA architecture, by providing three different contributions: i) identifying a sub-set of FLAVIA operational scenarios, in which the main system features (i.e. flexibility, modularity, virtualization) do clearly emerge; ii) detailing these operational scenarios into FLAVIA system uses cases for users, developers, manufacturers and operators; iii) refining the FLAVIA system requirements on the basis of the in-depth analysis of use cases and initial architecture design and prototyping activities.

After a brief introduction enlightening the differences between this document and the previous deliverable D211, the rest of the document is organized into four main sections. First, we summarize the initial design of the FLAVIA system, both in terms of service-oriented architecture (which has driven the functional decomposition of the wireless nodes, in order to come out with the system primitives), and in terms of components. Second, we revise the scenarios described in D211. We summarize the general situations under analysis and the motivations which justified each scenario proposal. Then, we map a few scenarios into concrete use cases of the FLAVIA system, showing the system adaptations to different user/operator inputs or environment stimulus, and identifying non-behavioral requirements. Third, we generalize the service analysis of scheduled-based and contention-based systems, by merging some services and functionalities into common core services and by leaving the other services as optional services. Finally, we revise the requirement list by proposing two abstraction levels of requirement description, by adding non-functional requirements, and by mapping each functional requirement into system primitives and/or add-on programmable functionalities.

1 Introduction

On the basis of the initial design of the FLAVIA system architecture, we revised the scenarios and the requirements identified at the beginning of the project activities. While the first scenario and requirement analysis was mainly targeted to the architecture design, the main goal of this document is providing inputs for the architecture revision and for the preparation of the demonstrators, by testing the system flexibility, modularity and virtualization capabilities in different use cases.

In D211 we started from the description of the FLAVIA exploitation possibilities, focusing on the analysis of *lack of functionalities* of current systems and *desired extensions*. In order to catch the widest set of FLAVIA system requirements, we followed a brainstorm-like scenario identification strategy, without coordinating the scenario proposals provided by different partners. The functional extensions envisioned in each scenario have been then decomposed into a functional hierarchy: from global <u>services</u> offered by the 802.11 and 802.16/LTE technologies to the upper layers, to PHY/hardware level <u>primitives</u>. Finally, these functionalities of different complexity levels have been mapped in a list of functional requirements, in terms of *configuration functions* (working on MAC/PHY parameters), *frame forging functions*, *medium access functions*, and *virtualization functions*.

Now, starting from the FLAVIA system described in D221, we try to understand the system behaviour in response to specific user/operator inputs and environment stimulus triggering the adaptation of the system in different use cases. To this purpose, *we select a sub-set of the initial operational scenarios in which we can envision different primary actors (operator, manufacturers developers and end users) interacting with the FLAVIA system for gaining different benefits*. The operational scenarios describing general situations and programmability exploitations have been revised in terms of concrete use-cases of the FLAVIA system, by separating the *potential approaches* for supporting the FLAVIA adaptations from the *procedural decisions* to be programmed for dealing with each use case. While the approaches involve the FLAVIA control sub-system (in terms of internal configuration, inter-node signalling operations and consistency), the procedural decisions involve the FLAVIA behaviour sub-system and can be mapped into services/functions/state machines to be customized. Therefore, this analysis has provided further inputs for eliciting the primitives of the FLAVIA system, both in terms of control system primitives (loading, running, stopping services and signalling protocols) and wireless MAC processor primitives (i.e. basic functions on the PHY/hardware).

We also made some efforts for generalizing the functional analysis of contention-based and scheduled-based systems (when possible), removing redundancies from the previous document, and for making more uniform the presentation of the final requirement list.

2 Initial breakdown of the FLAVIA system

The first iteration of the FLAVIA architecture specification has been carried out for introducing full flexibility to future wireless access technology, by extending the configuration interface exposed to the higher layer from *tunable parameters* to *programmable procedural decisions*. To this purpose, we identified a set of important MAC layer sub-tasks (the replaceable modules of the initial architecture design) as elementary programmable units, which extend the concept of layer 2 services. These services can be, in turns, decomposed into simpler sub-routines and functions, that can be layered according to the abstraction level of the system resources and parameters they work on. On the basis of this functional analysis, we derived a new architecture for programmable wireless interfaces, in which the traditional MAC/PHY layers are replaced by: i) a wireless MAC Processor, which exposes fixed *primitives* for managing frame transmissions and hardware events; ii) three layers of functionalities with different complexity (*state machines*, *functions*, and *services*), exposing programmable interfaces.

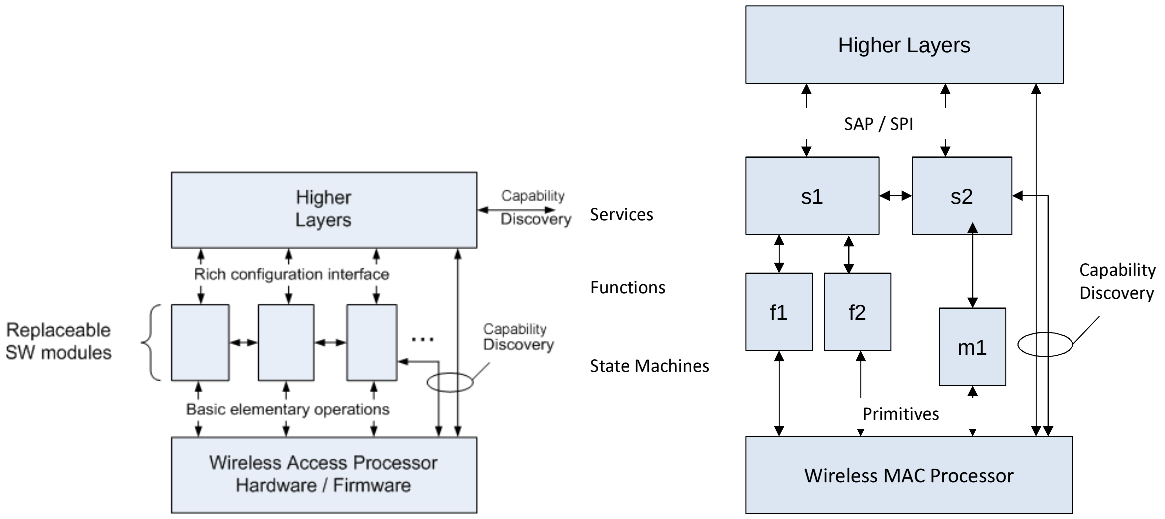

Figure 1: From the original architecture view to the functional layers of the first architecture specification, exposing Service Access Points (SAPs) and Service Programmable Interface (SPI)

2.1 FLAVIA services

The envisioned service-oriented architecture of the FLAVIA system includes the following core services:

- *Transport*: It provides the operations for queuing the frames coming from the upper layers and delivering the frames over the wireless medium. It interacts with the QoS policy service, for tuning some configuration parameters of the medium access function and employing different queuing policies according to the traffic type.

- *QoS policy*: It defines the queuing and priority policies according to the application requirements.
- *MAC Management*: It includes the signalling messages and the decisions for link management operations, such as link establishment, authentication and association, beaconing, etc.
- *Monitoring*: It collects statistics on system performance and wireless channel observations to be provided to other services for internal configurations and optimizations.
- *PHY Resource Management*: It allows the dynamic configuration of PHY parameters, thus including rate adaptation (in terms of selection of an available modulation and coding scheme) and power tunings on the basis of an optimization strategy.
- *Power Saving*: It decides on the activation or deactivation of the PHY layer and on the tuning of the transmission power in order to save energy, according to user and application requirements.
- *Application Optimization Support*: It allows exposing internal MAC parameters to the upper layers for enabling cross-layer optimizations.
- *Virtualization:* It allows implementing multiple mobile networks (even adopting different protocols) using the same node hardware.

These modules can in turn use simpler functions (such as queuing management functions, frame forging, medium access functions, etc.) which can be invoked by multiple services in the same form on in terms of specific implementations.
Additional services can be added for dealing with technology-specific capabilities of different platforms.

2.2 FLAVIA components

The system architecture includes a functional sub-system, implementing the system behavior, and a control subsystem, required for configuring the system and guaranteeing its consistency (details about the initial architecture specification and relative interfaces are provided in D2.2.1).

At the lowest functional layer, there is a special architecture component, called wireless MAC Processor (WMP), that is responsible of interacting and scheduling actions on the platform layer, by executing an abstract program specified in terms of a state machine working on the available primitives. On top of this layer, there is a layer called function container that runs data organization and elaboration functions, in terms of frame forging, queue management, definition of signal messages, performance statistics, and so on. This layer interacts with the lower functional layer by passing frames to be transmitted by the platform and/or by invoking the system primitives. At the highest layer, there is the service container in which different layer 2 sub-tasks are executed in terms of independent (replaceable) modules. Each service may expose a customized interface to the higher layers and can invoke functionalities available at the lower layers. Service and functions are defined in terms of generic bundles in a repository, from which they can be instantiated into the relative containers. The repository is part of a more general system information data base, which aggregates, abstracts and shares different data types, by communicating with all the system functional layers.

A transversal control plane works on the control of the functional layers (i.e. on the service/function logic and data structures), dealing with: i) service configuration, that is adding/removing service and function modules; loading/unloading running instances of services and functions; modifying/updating/reconfiguring service and function parameters (on the fly or offline); ii) consistency management, that is exporting services definitions to other nodes; verifying service conflicts; guaranteeing inter-nodes and intra-node consistency; iii) resource virtualization, that is managing virtual inter-faces; enabling virtualized services and functions; iv) data handling, that is collecting and storing system performance statistics; defining system state data; enabling function and service inter-communication.

3 Definition of Use Cases

3.1 Summary of the Considered Operational Scenarios

In D211 we selected a set of exemplificative scenarios, covering several limitations emerged so far for current wireless access technologies. An **operational scenario** has been defined in terms of a network topology, a PHY layer, and/or an application configuration context, in which current technologies exhibit clear limitations and FLAVIA architecture can enable innovative solutions for performance benefits. We summarized the weaknesses of the current technologies in terms of *rationale* for the scenario selection; we discussed solutions for these limitations in the *benefits and innovation* section; we clarified why these solutions cannot supported by current standard in the *issue* section; we finally illustrated the approach for boosting innovation under the FLAVIA paradigm in the *approach* section.
Since the organization of base stations, relay and mobile nodes on a single-cell and multi-cell coverage area (i.e. the network topology) is often a key aspect for characterizing each technology performance, we also grouped the operational scenarios referring to the same network topology in **network contexts**. In addition, we gathered the network contexts by also considering the different paradigms of channel access (at least in terms of basic functionalities on top of which other extensions are possible), as scheduled-based and contention-based systems.
Impairments of current technologies (not necessarily limited to performance impairments) have been considered by identifying *lack of functionalities*, while benefits enabled by FLAVIA have been considered as *additional available functionalities*.

As far as concerns the scheduled systems, we distinguished single cell, multi-cell and hierarchical network topology contexts. In the *first context*, we grouped all the operational scenarios dealing with single-cell independent optimizations. These scenarios are characterized by the need of performing advanced Radio Resource Management (RRM) algorithms, for increasing the spectral efficiency with novel scheduling solutions and advanced PHY technologies (such as multi-antenna and beam-forming), while containing the bandwidth wastes due to signaling. In the *second context*, we considered all the operational scenarios dealing with network-wide performance management or coexistence with overlapping networks. The scenarios are characterized by the need of performing distributed or coordinated RRM mechanisms for limiting the inter-cell interference and improving the performance of users experiencing bad channel conditions. In the *last context*, we considered the operational scenarios referring to overlaid cells, with heterogeneous capabilities (in terms of radio coverage, but also base station complexity). Under this context, we have analyzed the additional functions required for macro-cells and femto-cells coordination.

As far as concerns the contention-based systems, we distinguished single-cell, overlapping cells, multi-service mesh and niche network topology contexts. Again, under the single-cell contexts, we grouped all the operational scenarios dealing with independent "customizations" of ad-hoc systems for pursuing a number of different goals, such as prioritization of different traffic classes, punishment of selfish nodes, capacity optimization, and so on. Heterogeneous requirements, ranging from the configuration of the access parameters to the definition of complex per-flow or per-node queue management policies have been identified. In the second network context, we grouped all the scenarios referring to densely populated areas, in which the presence of multiple overlapping WLANs may cause poor wireless performance due to interference and collisions of uncoordinated packet transmissions. For improving the network performance in this context, we analyzed the functional requirements emerging for dynamically managing the radio spectrum, selecting the best operational channel or operating frequency hopping, performing load-balancing, aggregating or disaggregating the available bandwidth in multiple channels, and so on. In the third context, we grouped the scenarios dealing with the deployment of complex infrastructure-independent network topologies (such as municipal or emergency service networks). Since the native 802.11 technology does not support any form of coordination among the network nodes, we analyzed the specific functional requirements for implementing different forms of distributed allocation policies, advanced network-wise mechanisms for service differentiation, network virtualization mechanisms, and so on. The last network context groups two operational scenarios referring to special topologies, whose deployment represent somehow niche applications. For these scenarios, we identified special functional requirements, not emerged in the other contexts.
Overall twenty-three (23) scenarios have been built up by the FLAVIA partners. Each scenario descriptions reported in the sections above has been summarized in the following table, where we summarize (in the *description* column) the benefits enabled by the FLAVIA system. Note that scenario S2.1.2 (already included in D2.1.1) has been slightly extended on the basis of the contributions of the new AGH partner.

Scenario	Title	Description
S1.1.1	Multicarrier & load balancing strategies	Maximization of aggregate sector/deployment throughput, while minimizing sector users outage
S1.1.2	Feedback radio resources management	Minimizing the performance degradation due to the shortage of feedback channels in case of massive number of active MSs in the same sector.
S1.1.3	Extending scheduled systems flexibility through user virtualization	Scheduling resources when two or more applications originating at the same mobile station are characterized by very different QoS requirements.
S1.1.4	"Swiss Army Knife" Network Nodes	Managing wireless resources when the operator has to react in a timely manner on sudden new application or deployment requirements.
S1.1.5	API for upper layer adaptation	Optimizing the application performance at the mobile side, by means of radio-specific measurements

		provided by the wireless card.
S1.2.1	Network Nodes Resources Virtualization	Roll-out of new technologies on existing base station hardware or coexistence of different operators sharing network node s (i.e. base stations), with heterogeneous technologies or technology releases.
S1.2.2	Cooperative allocations for femto/macro cells	Interference control in a macro-cellular system overlaid with femto-cells, devised to extend network coverage in indoor environments.
S2.1.1	Intra-WLAN PHY-based traffic differentiation	Supporting video traffic when all nodes in range of each other experience different radio conditions. In presence of traffic with different delivery requirements (e.g., I, B and P frames of MPEG codec), the MAC translates packet priority into heterogeneous PHY transmission modes.
S2.1.2	Network robustness	The FLAVIA architecture is shown to be robust to degraded channel conditions, node misbehavior, as well as intra- and inter-node misconfiguration.
S2.1.3	Multi-rate selection schemes for emerging PHY layers	Selecting the best possible transmission mode, in terms of number of parallel antenna streams and per-stream transmission format.
S2.1.4	Network analysis and monitoring	Equipping a node with advanced sensing and monitoring functionalities for better understanding its environment..
S2.2.1	Interference-free networks	Managing interference in case of overlapping networks, by sensing multiple channels and selecting the best available channel and modulation scheme.
S2.2.2	Load-based OFDM carrier allocation with concurrent WLANs	Managing interference from multiple OFDM-based co-located networks, under time-varying load conditions, by means of dynamic carrier allocations.
S2.2.3	Backhaul bandwidth aggregation	Sharing backhaul bandwidth in a high density deployment of WLANs broadband access gateways, under access/security mechanisms for preventing unauthorized access.
S2.2.4	Broadband Hitch-Hiking	Saving energy at the AP and DSLAMs side, by going to sleep for some time when the WLAN broadband gateway does not have traffic.
S2.3.1	Multiple Virtual Networks	Creating multiple virtual networks, each one dedicated to a specific (prioritizable) service with separate signaling network with dedicated characteristics
S2.3.2	Infrastructure-less and Infrastructure-independent Mesh for emergency services	Self-configuring mesh networks of mobile nodes, customized for audio and video traffic transmission (including reliable groupcast transmission) under strict QoS requirements (in terms of throughput, packet loss and delay, etc.).
S2.3.3	Video support in 802.11-based mesh	Coexistence of data and video traffic in the same network. The priority of video frames is related to the

	networks.	delivery requirements in terms of experienced quality, and may change depending on network conditions.
S2.3.4	Distributed allocations in mesh networks	Minimizing inter-flow and intra-flow interference when networks nodes not fully connected use the same radio channel and can support heterogeneous transmission rates.
S2.3.5	Advanced multi-antenna techniques	Optimizing the configuration of the MIMO PHY-layer in mesh networks with a propagation environment rich of multipath, where data flows activate/deactivate dynamically.
S2.3.6	Indoor location	Using multiple APs as a distance triangulation system, by estimating the distance from each AP in terms of round-trip time calculation..
S2.4.1	Long-distance links	Automatic tuning of random access protocol parameters when link distances can be long and heterogeneous for different neighboring stations, with fixed or mobile nodes.
S2.4.2	Highly noisy and attenuated environment	Using relay nodes for improving link reliability in highly-noisy or attenuated propagation conditions.

Table 1 – List of scenarios

The detailed analysis of the extended scenario S2.1.2 is provided in the following table.

Scenario 2.1.2	
Name of the scenario	***Network Robustness***
Rationale	*Network robustness is crucial for operator's perspective (lower OPEX). Since programmable nodes intrinsically add the potential for misconfiguration, it is important providing mechanisms of punishing or incentivizing specific behaviors for avoiding performance degradation.*
Scenario description	*We consider an 802.11 network where the access point aims to enforce particular fairness or access policies. The access point may require particular measurements to assess which nodes are misbehaving and may want to take special actions in the event that stations are found to be misbehaving, such as disassociation, failing to generate ACKs or even jamming transmissions.*
Benefits and innovation	*The FLAVIA platform provides access to better measurements (such as the ones provided by the SuperSense service) to identify critical network conditions and misbehaving nodes, thus enabling the support of the following mechanisms:*

	• 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)
Issues	*Standard technologies are not adaptive. Moreover, they do not allow the possibility of carefully timed actions such as ACK dropping or jamming (that might be effective tools for punishment).*
Approach	*We propose different mechanisms for guaranteeing network robustness to node misbehaviors or conflicting configurations. As an example, we consider a scheme that controls ACK generation as a tool for punishment of misbehaving nodes. In the design of FLAVIA we will also facilitate other countermeasures, such as jamming.*

3.2 Selected Use Cases for scheduled systems

Among the different scenarios proposed for scheduled systems, we selected some key scenarios in which the FLAVIA architecture may bring benefits for different actors (namely, operators, developers and manufacturers).

As far as concerns *operators*, one of the most interesting applications is undoubtedly the virtualization of the radio access network, which can enable different operators to share the same physical infrastructure. In comparison to previous solutions, FLAVIA allows to program the infrastructure partitioning, while maintaining the possibility that *each operator performs independently its configuration and optimization strategies*.

As far as concerns third-party developers, we expect that the most crucial component affecting system performance is the scheduling/allocation scheme (i.e. the RRM scheme). Despite the fact that current technologies usually employ very basic solutions, more sophisticated schemes with different complexity and signaling overhead can bring significant capacity gain. FLAVIA allows separating the RRM scheme definition from the implementation of the network nodes, thus enabling the possibility that *third-party developers can propose RRM solutions to be deployed on different hardware platforms exposing the same programmable interface*.

Finally, manufacturers can differentiate their products by implementing different sets of the FLAVIA programmable primitives. A mobile card able to perform advanced measuring and monitoring functionalities can bring performance benefits to the users if the operator is able to exploit such functionalities for advanced resource assignment policies. Therefore, the FLAVIA paradigm will bring *new challenges for wireless interface manufacturers, in order to support as efficient as possible the set of FLAVIA primitives selected according to the manufacturers opening strategy*.

3.2.1 Virtualization for RAN Sharing [from S1.2.1]

The massive growth in mobile broadband traffic has sent shockwaves through the telecoms industry. Operators are struggling to find cost-effective ways to meet this demand. Analysis of a typical CAPEX model reveals that a majority of the upfront costs (70%) are related to establishing coverage (i.e. access related CAPEX). Market surveys indicate that different kinds of mobile infrastructure sharing are already deployed by over 65% of European operators and this trend will expand in the future.

Forecasted future mobile networks requirements together with current pressure on operators ROI position RAN sharing evolution as a 3GPP future key area, expected to usher in new paradigms in network roll-out strategy.

There are different approaches to realize dynamic RAN sharing:

- Pre-defined agreement among the operators on the parameters which define the RAN *resources split* and corresponding *scheduling policies* to be applied.
- Dynamic negotiation of RAN sharing agreement conditions based on current and forecasted resources needs, base station *virtualization capabilities*, etc..

There are also a number of procedural decisions to be taken:

- RAN Sharing service start time and duration according to the agreed conditions.
- Extension of flow and congestion control mechanisms to consider a new operator
- Required changes on traffic classification and queuing
- MAC scheduler modification considering policies and resource sharing agreements

In the following we describe a typical system behavior based on a dynamic RAN sharing request and generic procedural decisions.

Use Case: Virtualization for Dynamic RAN Sharing
Scope: Illustrate the Base Station system reconfiguration needed for dynamically sharing available radio resources on demand.
Primary Actor: A virtual operator requests resources on demand from the network infrastructure owner.
Success Guarantees: New virtual operators can be added, guaranteeing isolation from previous ones.

Main Timeline: 1. Virtual operator requests to infrastructure owner usage of resources for a specific period of time and specifying the data transmission needs (amount of resources, policies, etc.) 2. Admission Control checks feasibility of accommodating the RAN sharing request based on network load metrics 3. If the admission control function determines that it is not possible to accommodate the request the outcome is signaled to the requesting operator. 4. If the request is accepted the transport channel management function configures the required radio resources sharing settings as specified in the request. 5. The system then sets up the traffic classification function to be able to differentiate the traffic from the different operators. 6. Queue management needs to be updated next to configure new queue settings as needed 7. If a scheduling policy different than the one already implemented is required, the QoS Policy/transport service is adapted to accommodate the additional scheduling policies requirements. 8. Once the system is set up the virtual monitor will regularly check the RAN sharing process against the agreement with the virtual operator request and trigger any necessary re-configuration corrective actions when risk of agreement violation is detected.
Non Behavioral Requirements: - Specifying operator requests and verifying agreement violations

3.2.2 Deployment of customized RRM schemes [from S1.1.1]

The need for high performance personal mobile broadband is constantly raising within the deployed 3G/3.5G networks. As such, advanced PHY layer operations based on multi-carriers and dynamic bandwidth management has to be supported.
The load balancing, namely the assignment of mobile stations into carriers, can be referred as a typical Radio Resource Management (RRM) task, which can be achieved using different balancing strategies, including (among others): maximization of aggregate sector/deployment throughput, minimizing sector users outage scenarios (where their actual rates less than their Service License Agreement (SLA) profile, etc…

Within current scheduled systems access protocols (such as LTE, 802.16e, 802.16m), Load Balancing RRM algorithms are left out of the standards in order to allow different design and implementations for vendors. As so, each BS vendor has its proprietary implementation where currently there are no generic Service APIs specified to/from load balancing service (functionality) to other involved MAC modules, such as Admission Control and Scheduling, to allow high level of programmability.

In order to support the possibility of RRM scheme deployments by third-party developers, the RRM scheme has to be organized in terms of different interacting modules, such as scheduler, allocator, traffic shaper and queue manager.

There are <u>different approaches</u> to support the deployment of programmable RRM schemes:

- Pre-defined agreement on the feedback measurements and signaling mechanisms, which provide the input parameters for the RRM algorithms;
- Dynamic and/or heterogeneous feedback signals according to different mobile node capabilities and cell load conditions.

There are also a number of <u>procedural decisions</u> to be taken:

- Definition of system users, which may distinguish actual users or elementary flows of the same actual user;
- Definition of load and activity metrics, to be considered by the load balancing decision;
- Load balancing procedure (BS initiated or MS initiated handover support, hysteresis thresholds, etc.);
- Scheduling scheme;
- Resource allocation maps according to the scheduler indications.

In the following we describe a typical system behavior for programming a new RRM scheme.

Use Case: Deployment of customized RRM schemes
Scope: Illustrate the Base Station and Mobile Stations sub-tasks interacting for making programmable the RRM scheme.
Primary Actor: A manufacturer or a third-party developer which programs a new RRM scheme on the FLAVIA system.
Success Guarantees: New schemes can be easily plugged on the architecture, without requiring any additional interface.
Main Timeline: 1. A developer access the system Service API at the Base Station side for defining a new RRM scheme. 2. The developer specifies Data handling functions (abstracting system resources, users and feedback measurements) on the basis of the FLAVIA primitives. 3. The developer defines a traffic shaping function, a queue manager, a scheduler, and an allocator interacting with the data handling functions. 4. The developer programs the measurement and signaling modules to be loaded at the Mobile Station side. 5. The system verifies that the new modules can be supported by the base stations and uploaded on the mobile nodes. 6. If the new RRM scheme is accepted, the system binds the new system functionalities and exposes a new Service Access Point for accessing these functionalities.

Non Behavioral Requirements:
- New service support has to be verified at a base station, regardless of mobile station heterogeneity.

3.2.3 Measurements-based application optimizations [from S1.1.5]

In order to support advance RRM solutions, mobile stations have to actively cooperate to base station decisions by means of advanced measurement, monitoring and signaling functionalities. This implies that manufacturers have to open part of their internal (somehow "private") parameters to operators and developers. For example, the USB dongle providing the radio connectivity (for instance WiMAX or LTE) has to provide to the host some radio specific parameters. These parameters could then be used by the application layer (or by the MAC/RRM layer in the feedback messages to the base station) for improved experience of optimized resource usage.

By providing an interface to the host applications, the USB dongle can enable new concept of RRM or application layer type of control. The development of such an interface extends the principle of connection manager which often include only basic functionalities. Current connection manager provides basic capability of interfacing with the 4G USB dongle such as connect/disconnect and a report of an estimated value of the throughout or SNIR.

Also for this use case, there are <u>different approaches</u> that can be followed for exposing the extended dongle interface:

- Pre-defined agreement with the infrastructure vendor or with the application provider, in order to respond to specific RRM or content-adaptation requirements;
- Vendor-specific openness strategy, as a tradeoff between protection of vendor internal design and market potential exploitations.

There are also a number of <u>procedural decisions</u> to be taken:

- Data aggregation and filtering within the wireless adapter;
- Data sampling and representation.

In the following we describe a typical system behavior for enabling interactions between applications/users and low-level data and parameters of the wireless adapters.

Use Case: Measurement-based Application Optimization
Scope: Illustrate how manufacturers can add value to their wireless interfaces by opening advanced interfaces exploitable by the applications and/or operators.
Primary Actor: A user or an application accessing the advanced configuration manager of the wireless interface for improving different types of system performance.
Success Guarantees: Applications can easily adapt to the physical conditions of the wireless adapters, thus natively supporting a form feedback from the lower layers.

Main Timeline: 1. The user accesses the advanced configuration manager of the wireless adapter for specifying the low-level data to be available for applications and other services. 2. The user may also load specific filters for triggering the data acquisition and/or aggregating internal data before exporting the results to the host. 3. The system specifies if all the primitives required for data acquisition and all the conditions required by the filters are supported. 4. If the data collection specified by the user can be supported by the system, the wireless adapter starts collecting data and passing data to the host according to the user-defined policy. 5. A measurement monitoring service is started on the host for receiving the data and exposing the data to the application layer, by means of a specific service access point. 6. Applications (and/or RRM services) revealing that a measurement SAP is available can access the SAP for reading low-level data.
Exceptions: - Exception signals can be generated because of data unavailability or data incongruences due to acquisition problems**.**
Non Behavioral Requirements: - The timings of the host-adapter interface have to be congruent to the data acquisition timings.

3.3 Selected Use Cases for contention-based systems

Also for the contention-based systems we selected a few operation scenarios showing the key FLAVIA features that allow to respond to the programmability requirements of different actors (operators, developers, manufacturers and applications).

As far as concerns *operators*, virtualization is again of the most interesting use case enabling advanced services and service differentiation. However, differently from scheduled-based systems (where virtualization is mainly devised in sharing infrastructure nodes between different operators), here we analyze the possibility for operators to *virtualize wireless adapters at the mobile nodes, for managing multiple links to different Access Points*. Another crucial aspect for operators is implementing add-on services, such as *preventing and correcting node selfish behaviors* enabled (or extended) because of FLAVIA programmability.

As far as concerns third-party developers, we expect that the most crucial component affecting system performance is the medium access function and the data transport services built on top of this function. Therefore, regardless of the standardization activities or in parallel to these activities, an interesting use case for developers and researchers is programming new advanced data transport services tailored for specific network topologies (such as mesh networks with several potential hidden nodes). In fact, the FLAVIA system allows to program time-stringent operations (such as the medium access rules) in terms of state machines interacting with both the trans-receiver and data transport service. Therefore *third-party developers and researchers can propose MAC solutions and MAC/PHY interactions to be easily updated or run-time adapted on the same wireless adapter.*

Finally, applications can exploit the possibility to access to low-level data and PHY configuration capabilities for significantly improve their performance. To this purpose, advanced monitoring services have to be defined on top of the FLAVIA primitives opened by the manufacturers, while *application or service developers have to map these new monitoring capabilities into performance benefits perceived by the users*.

3.3.1 Virtualization for backhaul bandwidth aggregation [from S2.2.3]

The global bandwidth demand is exploding through the multiplication of mobile devices (smartphones, tablets, etc.), connected equipment (ebook readers, Internet TV) and content (cloud-based technologies, video on demand streaming, etc.). Despite novel access technologies, such as LTE and the enhanced releases of the 802.11 standard, are being developed to address this increasing demand, the rate at which these solutions are deployed is hardly matching the volume of connected devices adopted by users. Therefore, transitional technologies have to be designed to cope with this unbalanced situation.

A promising proposal of such transitional solution seeks to maximize the use of the unused WiFi bandwidth (traditionally referred to as WiFi offloading), by allowing off-the-shelf hardware to simultaneously connect to multiple WiFi access points (traditionally, the DSL routers) and thus obtain more bandwidth in dense areas such as cities. This capability is achieved by virtualizing the client's network interface. An operator, by advertising this service for its home gateways, could offer the necessary software and access credentials to customers that desire more traffic capacity but do not have a technical edge (such as Fiber connectivity or sufficient DSL synchronization rate) to get more bandwidth to their household. Peering agreements could be established between operators to provide local bandwidth exchange between neighbor gateways.

Previous considerations correspond to different approaches that can be followed for enabling bandwidth aggregation, involving:

- agreements between operators to provide local bandwidth exchange;
- advertising of the aggregation possibility;
- managing of multiple links with a single radio interface (e.g. by means of power saving).

There are also a number of procedural decisions to be taken:

- scheduling the switching from an access point to an adjacent one;

- buffering and prioritizing the pending traffic at each access point;
- backhaul link capacity estimation;
- etc.

An example of system behavior for managing bandwidth aggregation is summarized in the following table.

Use Case: Virtualization for backhaul bandwidth aggregation
Scope: Illustrate the virtualization of the wireless client adapter for supporting bandwidth aggregation.
Primary Actor: An operator providing additional bandwidth to customers using dedicated software and off-the-shelf hardware.
Success Guarantees: Bandwidth increase and fairness for the customers as well as non-customers in range.
Main Timeline: 1. A customer with a device having the bandwidth aggregation feature activated is connecting to a wireless (home) network provided by an Operator offering the bandwidth aggregation service. 2. A second (foreign) access point providing the same service is in radio range. 3. 2 virtual interfaces are created and are connecting following the IEEE 802.11 standard protocol to each physical access point/router. 4. Traffic is downloaded from both access points, alternating the use of the virtual interfaces according to a TDMA-like scheme. 5. User traffic pertaining to the foreign access point is monitored by tracking the data visible on the channel. This is required in order to ensure fairness is preserved, i.e. the foreign user is not being deprived of the contracted bandwidth. 6. Traffic of the backhaul link is also estimated in order to track the available capacity of the each connection. This is done through traditional bandwidth measurement tools.
Non Behavioral Requirements: - No constraint on the number of virtual interfaces at the mobile side.

3.3.2 Activation of an advanced probing service [from S2.1.5]

We consider a network scenario in which FLAVIA nodes are equipped with an advanced monitoring service (called SuperSense SPS) able to compute a stable estimate of the link quality (i.e., frame reception probability) even under high traffic load. The advanced monitoring service is based on a TDMA-like mechanism for isolating the measurement intervals and preventing collisions between data and probe frames.
A different service (or an higher-layer application) requires to start the SPS service and to have access to the SPS estimates.

There are different approaches to realize this use case:

- Pre-defined agreement among the nodes on the parameters which define the super-frame organization of the TDMA slots used for probing.
- Dynamic activation of the SPS service according to the information broadcast by a coordinator (cluster head or Access Point).

There are also a number of procedural decisions:
- Instant of time and duration of the active monitoring activity according to the requirements of the service requiring the advanced estimates (data transmission, QoS).
- Whether to activate or not the SPS service, according to the nodes that can support it.

We describe a typical system behavior based on the dynamic activation of the probing service and generic procedural decisions.

Use Case: Activation of an advanced probing service
Scope: Illustrate the system behavior for activating and accessing an available service.
Primary Actor: An higher layer application or a different service making service requests to the advanced probing service.
Success Guarantees: The higher layer application (service) may utilize the advanced per-link estimates computed by the probing service.
Main Timeline: 1. The higher layer application (service) requires to interrogate the advanced probing service. 2. If the service is not active, the system tries to start the service. If the service is already active, a link to the probing service interface is established. 3. If the system supports the advanced probing service, it tries to start the synchronization process by looking for synchronization parameters (i.e. super-frame organization) broadcasted by a peer service running on a neighbor node (acting as cluster head). 4. The system sends a message for signaling the activation of the new service to the cluster head. 5. If the cluster head receives the activation message, it computes a new slot assignment and updates the messages describing the super-frame schedules. 6. If the system receives the new super-frame scheduling message including its identifier, the probing service can be activated. 7. According to the scheduling policy, the system starts periodically broadcasting probe messages which contain the neighbor list (built on the basis of similar messages got from neighbor nodes) and the corresponding packet reception probabilities. 8. Upon a new probe is received, the system updates the internal information about the link that can be established with the originator and the links of other nearby nodes. 9. The parameters (channel assignment, data rates) and estimates (link quality) available per each link are passed to the service triggering the service activation and updated at each subsequent service request.

Non Behavioral Requirements:
Timestamps in the probing messages, with nanoseconds accuracy.

3.3.3 Punishment mechanisms for misbehaving nodes [from S2.1.2]

An important service to be offered by operators using contention-based access technology is the possibility of preventing selfish behaviors of its clients. For this purpose, the access points installed by the operators need to employ advanced monitoring functionalities, able to detect anomalous behaviors of the client nodes and to punish these behaviors. This add-on service can be advertised by the operator in order to encourage mobile nodes to use its network infrastructure (where a fair share of the resources is guaranteed).
There are different approaches that can be followed for enabling the support of this service. For example, the operator may assume that client nodes can in turns observe their punishment or can in general update their strategy on the basis of their utility. Alternatively, the operator may rely only on the observed node reactions (such as the contention window doubling as a consequence of collisions) for forcing a fair resource repartition without affecting the node strategy (that is per-configured by the user and cannot be dynamically updated). Different approaches can also be adopted for the monitoring service, such as passive channel observations, active probing, etc.

There are also a number of procedural decisions to be taken:
- the detection mechanism and the management of false detections;
- the punishment action (jamming, ack dropping, etc.).

Assuming that the nodes can change their strategies and that active and passive probing are simultaneously used (regardless of the specific procedural decisions), we can imagine that a network employing a punishment service for selfish nodes will behave as described in the following table.

Use Case: Punishment mechanisms for misbehaving nodes
Scope: Illustrate the possibility that operators deploy add-on services preventing selfish behaviors of the client nodes.
Primary Actor: An operator providing a punishment mechanism for selfish clients.
Success Guarantees: Nodes using lower contention windows stop their selfish behavior because of the punishment mechanism deployed by the operator.
Main Timeline: 1. The operator starts an advanced monitoring service (e.g. SuperSense) based on active and passive monitoring operations at the infrastructure Access Point. 2. The monitoring service estimates the wireless link quality established with nearby nodes and the interference which might be generated by external sources by means of active probing. 3. The monitoring service estimates the MAC contention parameters used by contending nodes by means of passive channel observations.

4. On the basis of link quality estimates and channel observations, the monitoring service at the operator AP detects a node using a minimum contention window lower than the other nodes. 5. The AP activates a penalty service for the misbehaving node. 6. The misbehaving node updates its MAC contention parameters for optimizing its utility. 7. As a reaction to the penalty scheme, the misbehaving node updates the MAC contention parameters, which converge to the use of a standard minimum contention window.
Non Behavioral Requirements: - The updates of the contention window values have to be slower than the observation time required by the monitoring service.

3.3.4 Deployment of MCCA-like data transport services [from S2.3.4 and S2.3.2]

We consider a network scenario in which a single radio channel is used and not all the network nodes are in radio visibility. The system needs to accommodate heterogeneous traffic, among which traffic that requires parameterized QoS support (i.e. requires low and stable end-to-end delay and low packet loss probability). Examples of this kind of traffic are VoIP or Video traffic.

This scenario has been somehow considered in several standardization extensions of IEEE 802.11, including IEEE 802.11s mesh reservation-based channel access method (called MCCA). However, we consider that an interesting FLAVIA use case is the immediate support of any standard amendment without waiting for the final approval and without being constrained by the final solution (for example, by easily extending DCF to MCCA and by also supporting the MCCA variants whose detailed descriptions is presented in D6.2 which have not been incorporated in the 802.11s standard).

The developer can program its Data Transport service with parameterized QoS, by defining the queue management policy, the traffic classification functions, the signaling messages and the medium access rules. Since nodes have to agree on a common data transport service, the usual pre-agreement or negotiation approach can be envisioned. Programming a data transport service also implies a set of procedures, such as:

- Managing conflicts between multiple channel access reservations;
- Responding to collision events;
- Selecting the most effective handshake access mode.

Once the new Data Transport service is built, applications can select standard DCF or the new transport service according to their requirements, as described by the following table.

Use Case: Usage of Data Transport service with parameterized QoS for reliable transmission of QoS-sensitive traffic

Scope: Illustrate how FLAVIA can support new medium access rules which are not included in the current standard
Primary Actor: An higher layer application (VoIP or Video traffic)
Success Guarantees: QoS-sensitive traffic is transmitted with acceptable quality
Main Timeline: 1. A new flow which requires QoS support appears on the FLAVIA node 2. If the MCCA service is not run on all nodes in the network, the FLAVIA node using special management frames tries to setup it. 3. On each node the service composition function is started. The FLAVIA node verifies that the MCCA service can be built (i.e. the service code is available in the repository, the functional dependencies are verifies and the state machine bytecode is available) and creates the running instances of all the required functionalities. 4. If any node does not support the MCCA service, the service can not be used for data delivery. 5. The FLAVIA node requests the route for the flow from the L2 routing service which should take into account that reservation-based channel access method (MCCA) will be used. 6. The FLAVIA node sends the MCCA reservation messages along the route and tries to establish reservation for the flow 7. If the reservations were established successfully they are used for data delivery.
Non Behavioral Requirements: 1. Common temporal reference for all the nodes of the network, with microseconds accuracy.

3.3.5 Power-hopping for enhanced PHY [from S1.1.3]

We consider the case of dense network deployments where nodes have similar channel conditions to the access point. In such circumstances it is expected that using the default 802.11 access scheme will result in high collision rates and consequently in reduced throughput performance. On the other hand, our previous analytical and experimental studies 0 show that, in the presence of the capture effect, both nodes that deliver packets at high signal strength and those whose transmissions are perceived at lower power levels can benefit from this effect. In particular, some of the packets resulting in collision will be successfully demodulated by the AP, therefore all contending nodes will experience an increased success rate and reduced number of retransmissions. This motivates the design of an enhanced PHY that improves the 802.11 MAC behaviour by periodically setting the transmission power of stations to dissimilar levels. Specifically, we design a power-hopping MAC that exploits the capture effect to mitigate collisions, thereby boosting the throughput.

Upon sending a frame, a node running the power-hopping service will choose with the same probability between a low and high transmission power level. This functionality is achieved by exploiting the capabilities of the FLAVIA system to control the TX power with a per-frame granularity. In what follows, we describe the typical behavior of a node executing the power-hopping MAC.

Use Case: Power-hopping for enhanced PHY
Scope: Illustrate how FLAVIA can support PHY-MAC interaction which is not supported in the current standard
Primary Actor: Higher layer applications
Success Guarantees: The network can achieve higher throughput performance
Main Timeline: 1. The power-hopping MAC is loaded on the node. 2. The module queries the information base for the power range supported by the hardware and permitted by the regulatory domain. 3. The module assigns the maximum allowed power to the P_{max} to be used for transmission at high level. 4. The node samples the channel with different power levels to establish the lowest employable power P_{min} that yields minimum loss rate at the selected MCS. 5. Whenever a new frame needs to be transmitted on the channel, the module selects with equal probability between P_{min} and P_{max}. 6. The selected power level is encapsulated in the frame descriptor and passed to the hardware along with the contention parameters and the outgoing data. 7. The procedure is repeated for subsequent transmission attempts.
Non Behavioral Requirements: - Power adjustments has to be performed by the end of the medium access delay of each frame.

4 Services

The FLAVIA system has been proposed for responding to three main requirements (modularity, flexibility, virtualization), that have been further decomposed into more specific system features. The definition of the services has been carried out for responding to the modularity requirement, since services represent the *high-level programmable unit* of the system, which can aggregate a set of reusable (and programmable) functions built on top of the system (non-programmable) primitives.

The extensive functional analysis of current technologies and extension proposals described in D212 led to the definition of core services common to both the scheduled-based and the contention-based systems, and to additional set of specific services which depend on the channel access paradigm (scheduled or contention-based access). These specific services mainly involve: i) the connection management operations, due to the different complexity of networks providing global coverage or local coverage; and ii) the coordination of inter-cell or intra-cell resource allocations and iii) the support of optimization strategies for the applications, which need to be somehow aware of the underlying access-paradigm. These services have been included in the definition of the general and technology-specific (802.11 and 802.16) architectures.

Because of the experience maturated in the service analysis and service interface definition within WP3 and WP4 activities, we improved the understanding of common features (and differences) between scheduled and contention-based systems and we tried to generalize the service analysis provided in D211.

4.1 Core Service Analysis

Feature #1 – Programmable Data Transport		
Feature description	*The data transport service provides forwarding and processing of user or control data before sending to the physical layer. Data can be transport with protocols to increase transport reliability, like ARQ and/or HARQ. Data can be encrypted. Different transport channels can be set.*	
Stimulus	*Higher layer call; user/operator interaction; MAC/PHY management call*	
Response	*Data forwarding to the PHY layer*	
Functionalities		**Priority**
1.1	*Encryption*	Normal
	• For user and control data	
1.2	*Segmentation*	High

	• Segmentation and concatenation of MPDUs	
1.3	*Backoff rules*	Normal
	• Contention window selection • Contention window update events • Backoff freezing / resuming events • Inter-frame space configuration for providing priority on medium access	
1.4	*Frame handshake*	Normal
	• Specification of reply frames to be sent without contention (such as ACK frames, CTS/DATA/ACK frames, and so on) • Tuning of inter-frame spaces for regulating reply priorities	
1.5	*Collision avoidance policy*	High
	• Mechanisms for physical medium sensing (energy-based, preamble-based, etc.) • Mechanisms for virtual medium sensing • Binary or multi-level channel state classification	
1.6	*Transport channel management*	Normal
	• Configuring transport channel operations • Create, modify and delete transport channels	
1.7	*Data flow classification*	Normal
	• traffic classifiers implementation • MAC header modification and dissecting	
1.8	*ARQ/HARQ*	Normal
	• Defining ARQ/HARQ mechanisms • Associating mechanisms to transport channels	
1.9	*Efficient audio/video delivery*	Normal
	• Multi-flow traffic splitting • Multi-path delivery strategies • Intra- and inter-flow differentiation	
1.10	*Group-cast transport*	Normal
	• management frames for reliable group-cast mode setup. • group-cast frames acknowledgement and retry logic. • Multicast addressing.	
1.11	*Performing one-hop reservations*	Normal
	• management frames for reservation setup, announcements, and tear down • Compatibility with stations not involved in the reservation process • Channel reservation logic based on QoS requirements • Admission control logic	
1.12	*Performing network-wide reservations*	Normal

	• Mechanism for set-up or tear-down a layer-2 path between non visible nodes • New multihop management frames conveying per-flow QoS requirements and reservation status • New multihop management frames for coordinating TXOP allocations	
1.13	*Polling*	Normal
	• Inter-frame space configuration for providing priority on medium access • Control frames for polling and polling replies • Control frames for notifying the status of node queues • Scheduler parameters access interface • Access the users SLA and QoS policy	
1.14	*Access to Channel Measurements*	High
	• Access to channel state information for channel-aware scheduling	
1.15	*Power Management*	Normal
	• Access to power management sleep cycles	

Feature #2 –Programmable QoS Policy		
Feature description	*Defining mechanisms for differentiating and negotiating traffic performance.*	
Stimulus	*Higher layer call; Data Transport call*	
Response	*QoS Profiles for the Data Transport service*	
Functionalities		**Priority**
2.1	*Estimate load metrics at the base station*	Normal
	• Implement traffic meters and classifiers	
2.2	*Collect traffic and PHY statistics*	High
	• Implement a meter for radio and traffic statistics • Save statistics in a data base • Collect info about the presence of neighbors and their activity (use a database and one or more meters)	
2.3	*Queue management*	High
	• Implement a database of loadable policies to be used for active queue management at MAC layer • Associate a policy with each traffic class	•
2.4	*Definition of the transport channel ACK policy*	Normal
	• Tag on-request the processing time of ACK packets • Artificial ACK dropping or postponing • ACK generation control • Accurate ACK timestamp (nanoseconds granularity) • ACK handshake configuration (per-frame or cumulative	

	ACK) • ACK frame configuration • Associating an ACK policy to a data transport service or traffic flow	
2.5	*Definition of the flow control policy per transport channel*	Normal
	• Accessing local or remote buffer state information • Accessing estimates of network operating conditions • Control frames for notifying queue status • Configuring sliding window parameters • Programming stop and go conditions • Associating a flow-control policy to a data transport service or traffic flow	
2.6	*Definition of the congestion control policy*	Normal
	• Enable/disable Active Queue Management (AQM) • Enable/disable TCP/IP Congestion Avoidance Algorithm • Programming congestion feedbacks (frame loss, delay, network conditions, etc.) • Programming control logic • Programming performance aspects to improve (lossy links, fairness, advantage to short flows, variable-rate links) • Associating a congestion control policy to a given data transport service or traffic flow	

Feature #3 –Programmable MAC management		
Feature description	*Set MAC signaling operations for network building and maintenance.*	
Stimulus	*User/Operator interaction*	
Response	*Upload/configure the MAC-Layer Management module*	
Functionalities		**Priority**
3.1	*Beaconing*	Normal
	• Advertising mechanism	
3.2	*Cell search*	High
	• Active/passive scanning • Measure and synchronize to a downlink signal according to the relevant physical parameters and method Extract physical estimators (received power, timing offset, frequency offset) • Select appropriate signal from cell search	
3.3	*Cell acquisition*	High
	• Converge physical loops (received power, timing offset, frequency offset)	

	• Check threshold and proceed / revert to cell search	
3.4	*Cell tracking*	Normal
	• Continue convergence of physical loops as in acquisition • Measure MAC layer estimators for cell quality	
3.5	*Neighbor and topology discovery*	Normal
	• Management frames for neighbor cells or peer node discovery • Management frames for topology discovery • Topology discovery protocol	
3.6	*Neighbor management*	Normal
	• Create neighbor table • Update neighbor table • Peer selection policy	
3.7	*Point-to-point Link establishment*	Normal
	• Active/passive scanning • Link set-up messages • Keeping multiple associations • Keep alive mechanism	
3.8	*Punishment functions*	Normal
	• Artificial ACK dropping or postponing • packets reordering in buffer • disconnect from network • jamming	
3.9	*Header customization*	High
	• Access to unused fields • Programmable header size and dissecting	
3.10	*Inter-cell coordination mechanism*	Normal
	• Frequency tuning • Time/resource assignment • Power allocation • -multiple antennas- coordination	
3.11	*Signaling messages for uplink reports*	Normal
	• Generate uplink report messages based on indications received by neighboring base stations	

Feature #4 –Programmable PHY resource management		
Feature description	*Set PHY parameters in order to select the best configuration as a function of the network environment.*	
Stimulus	*User/Operator interaction*	
Response	*Upload/configure the PHY Management module*	
Functionalities		**Priority**
4.1	*Configuration of the physical channel*	High

	• Carrier Selection • Tuning PHY power • Configuring the carrier sensing mechanism	
4.2	*PHY parameters tuning on a per-frame basis*	Normal
	• Choosing the modulation and coding format for each transmitting antenna • Antenna selection mechanism	
4.3	*Multi-antenna techniques support*	Low
	• MIMO mode selection (diversity, beam-forming, spatial multiplexing) • Setting the number of parallel streams • Performing opportunistic pre-coding operations • Nanosecond accuracy of receive/transmit frame time stamping • Control frames for notifying per-carrier channel state information (CSI) • Control frames for virtual MIMO support	
4.4	*Dynamic bandwidth allocation*	Normal
	• Spectrum scanning • Collection of spectrum utilization statistics • Channel selection	
4.5	*Dynamic bandwidth aggregation / disaggregation*	Low
	• Channel bonding • Changing the number of subcarriers used for OFDM modulations • Accessing different OFDM subcarrier groups as independent sub-channels • Nanosecond accuracy of receive/transmit frame time stamping • Wireless medium virtualization (for multiple WLANs or multiple data transport services).	

Feature #5 – Programmable Monitoring	
Feature description	*This service is aimed to measure continuously link quality for data transmission interfaces, in order to get all the important information to minimize interference; it contains all the activities related to what we defined as "Super Sense" or, more in general, scanning.*
Stimulus	*Data Transport Call*
Response	*Passing monitoring information with different "aggregation"*

	levels	
Functionalities		**Priority**
5.1	*Estimate the interference affecting the channel*	High
	• Implement a CSI mechanism	
5.2	*Active scanning*	Normal
	• New frames definition to be used for channel probing	
5.3	*Passive scanning*	Normal
	• Virtual interface for scanning • Error detection memory and statistic	
5.4	*Distance estimation*	Normal
	• accurately timestamp the transmit and receive trace-point at the radio modem level • sensing information support • line-of-sight estimation of the triangulating APs • attenuation estimation	
5.5	*Statistics / information collection*	Normal

	• collisions statistics collection for adaptive techniques
	• custom statistics collections
	• API for statistics availability
	• Information from the APs
	  o available bandwidth
	  o HW resources (CPU, power, etc.)	

5.6	*Monitor load condition on local interface*	Normal
	• Throughput monitor capability • busy/idle slots detection • interface saturation notification • Estimation of the number of contending stations • Estimate traffic load	
5.7	*Monitor signal conditions of PHY channel*	Normal
	• SNR • SNIR	
5.8	*Advanced sensing for scanning in parallel with transmission/reception*	Normal
	• Continuous scanning/sensing on different modulations/rates/TDM • Two radios	

Feature #6 – Programmable Power Saving		
Feature description	*Power saving target is to allow extended life time for (mobile) devices with limited battery power resources such as cell phones, laptops, PDAs, etc. Different scheduling policy and synchronization solutions for the activity/doze intervals has to be supported.*	
Stimulus	*User activation*	
Response	*Configuration of doze/active intervals*	
Functionalities		**Priority**
6.1	Power-saving support	Normal
	• Turning on/off the radio • Enable/disable sleep mode • Tuning transmission power	
6.2	Activity cycle management	Normal
	• Activity cycles configuration (periodic, random, event-trigger) • Control frames for synchronizing the activity cycles • Control frames for notifying traffic queue status • Periodic data scheduling • HARQ retransmission scheduling • Tracing traffic patterns	
6.3	*Data scheduling on activity cycles*	Low
	• Periodic data scheduling • HARQ retransmission scheduling • Feedback channel scheduling	
6.4	*BS-MS capabilities negotiation*	Normal
	• Power saving activity cycles synchronization	
6.5	*BS-MS Synchronization error handling*	Normal
	• Synchronization lost handling	
6.6	*Power saving configuration and monitoring*	Normal
	• Activity cycles parameters configuration (on/off durations, etc...)	
	• Activity cycles measurements	
6.7	*Information broadcasting*	Normal
	• Paging cycles management	

Feature #7 - Application Optimization Support	
Feature description	*The application optimization support service is meant for cross-layer optimization. It allows to configure the application parameters by providing the application layer with MAC/PHY real time statistics.*
Stimulus	*Application Layer call*
Response	*MAC/PHY configuration*

Functionalities		**Priority**
7.1	*Configuration of PHY parameters*	High
	• tuning of antenna(s), power, and coverage parameters	
7.2	*Configuration of MAC parameters*	High
	• Tuning of scheduler and allocator • Tuning of contention parameters	
7.3	*Handle traffic classes (virtual users)*	High
	• Implement a programmable packet classifier. • Set virtual downlink users (for each traffic type) at the BS side, to be scheduled independently. • Split the traffic generated by applications onto multiple connections at the MS side, each being dealt with as a (virtual) user	
7.4	*Collect statistics*	High
	• Implement a meter for radio and traffic statistics. • Save statistics in a data base	
7.5	*Queue management*	High
	• Implement a database of loadable policies to be used for active queue management at MAC layer • Associate a policy with each traffic class	•

Feature #8 – Virtualization		
Feature description	*Virtualization is the possibility to implement multiple mobile networks (even adopting different protocols) using the same node hardware.*	
Stimulus	*Operator Actions*	
Response	*Configuration of virtual node implementations*	
Functionalities		**Priority**
8.1	*Grouping of functions*	Normal
	• Defining a virtual interface	
8.2	*Implementation management*	Normal
	• listing, adding, removing, (de)activating implementations	
8.3	*Optimization support*	Normal
	• selecting a virtual interfaces according to an optimization criterion	
8.4	Resource Partitioning	*Normal*
	• Allocation of hardware/PHY and bandwidth resources (time-division, frequency-division, ..) • Service configuration (encryption, QoS, data transport)	

4.2 Additional Services

Feature #9 – Programmable load balancing		
Feature description	*Defining a load-balancing policy based on customized logic and metrices. The load balancing service provides the network means to reduce connection blocking and dropping probability by controlling handover decisions. The load balancing service associates connections/users to base stations based on the load at the available base stations.*	
Stimulus	*arrival of a new user/traffic flow; performance degradation of already admitted users; operator interaction*	
Response	*association of new users; forced handovers*	
Functionalities		**Priority**
9.1	*Estimate the load at the base station*	Normal
	• Implement traffic meters and classifiers	
9.2	*Inter-BS communication*	Normal
	• control frames for exchanging load information	
9.3	*MS status report*	High
	• Specify a set of classes for reports to be sent by the MS • Control frames for sending MS reports with different overheads	
9.4	*Policy management*	Normal
	• Implement policy database (that could be changed/updated)	

Feature #10 - Inter-cell coordination and cooperation		
Feature description	*The scarce resource of frequency bandwidth makes inter-cell coordination and cooperation algorithms increasingly important for the mobile network operators in order to further enhance data rates and capacity.*	
Stimulus	*New BS start-up; performance degradation due to congestion*	
Response	*Bandwidth allocation within the cell*	
Functionalities		**Priority**
10.1	*Inter-BS resource allocation*	Normal
	• Frequency tuning • Time/resource assignment • Power allocation • -multiple antennas- coordination	
10.2	*Interference management*	Normal
	• Meter the attributes of interference • Deploy intra-BS and inter-BS interference reports • Deploy MS reports on DL interference	

10.3	*Extend the signaling for UL power control*	Normal
	• Generate UL power control messages based on indications received by neighboring base stations	
10.4	*Intra-BS resource allocation for interference control*	Normal
	• Based on the inteference management reports, classify MSs to the FFR regions	

Feature #11 - Support for SON policies		
Feature description	*In order to provide support to SON operations, base stations and user equipments have to be able to collect, parse, and exchange active and passive measurements on traffic and channel conditions, e.g., by tracking the quality of a channel or by actively probing the capacity of a link. Measurements are used to run self-optimization algorithms whose output is used to update the configuration of base stations. Self-optimization targets radio resource management parameters, e.g., power settings and antenna parameters (MIMO). Furthermore, new services and even new entire sites should be handled in accordance to the plug-and-play paradigm, i.e.,by means of a Self-configuration tool. Finally, in case of cell failure, the surrounding cells should be able to cooperate in order to adapt their coverage range and handover the traffic of the cell in outage.*	
Stimulus	*New BS start-up; BS failure*	
Response	*BS auto-configuration*	
Functionalities		**Priority**
11.1	*Self-configuration of PHY parameters*	Normal
	• Environment (spectrum, interference, …) sensing; • Tuning of antenna(s), DL power and coverage parameters	
11.2	*Self-configuration of MAC parameters*	Normal
	• Tuning of the scheduler and allocator parameters	
11.3	*Optimize PHY parameters*	Normal
	• PHY optimization logic function, based on statistic on traffic and radio utilization and conditions, and neighbor's presence/activity	
11.4	*Collect statistics*	High
	• Implement a meter for radio and traffic statistics • Save statistics in a data base • Collect info about the presence of neighbors and their activity (use a database and one or more meters)	
11.5	*Channel probing*	High
	• Implement active measurement tools that can generate traffic and probe channel performance	•
11.6	*BS initiated handover*	High

	• Implement signaling to MS's and to/from neighbor BS's to force HO	
11.7	*React to cell failures*	Normal
	• neighbor cell monitoring system • re-run of the PHY optimization function	•

Feature #12 – Programmable admission control		
Feature description	*The admission control service estimates the available resources and decides whether to accept a connection without jeopardizing the QoS of existing connections. Admission control reserves resources for handover connections or/and high priority connections.*	
Stimulus	*New user arrival*	
Response	*Messages of admission acceptance of denial*	
Functionalities		**Priority**
12.1	*Estimate and predict the load at the base station*	Normal
	• Implement traffic meters and classifiers • Implement predictors of future traffic (e.g., handover connections, pick traffic)	
12.2	*Load scheduler and QoS parameters*	Normal
	• Scheduler parameters access interface • Access the users SLA and QoS requirements	
12.3	*MS status report*	High
	• Specify a set of classes for reports to be exchanged between the MS and the BS • Create and send control frames	
12.4	*QoS Policy management*	Normal
	• Implement policy database (that could be changed/updated) • Implement control messages to enforce the policy decision	

Feature #13 – Programmable mobility management		
Feature description	*Physical mobility shall be supported across the wireless network. The mobility management shall be optimized for low speeds (such as mobility classes from stationary to pedestrian) and provide high performance for higher mobility classes. In addition, the mobility support service shall maintain the connection up to the highest supported speed.*	
Stimulus	*Degradation of Signal Quality*	
Response	*Handover trigger event*	
Functionalities		**Priority**
13.1	*Transparent handover at low as well as high "speed"*	Normal
	• Fast channel tracking • MS initiated handover	

13.2	*Transfer data and control messages between base stations*	High
	• Export mobile station information and status from serving BS to target BS	
13.3	*Support soft handover*	Low
	• Allow MS to communicate simultanously with more than one BS	
13.4	*MS status report*	High
	• Specify a set of classes for reports to be sent by the MS • Create and send control frames	

Feature #14 – Coexistence support		
Feature description	*The coexistence support service includes all the policies and MAC enhancements required to allow joint operation of license-exempt operation of wireless networks. That includes the definition for a set of cognitive radio capabilities for both uncoordinated and coordinated coexistence.*	
Stimulus	*Detection of primary users*	
Response	*Interference control on primary users*	
Functionalities		**Priority**
14.1	*Inter-network collaboration and coordination*	Normal
	• Inter-BS coordination for interference reduction • Scheduling and transmission coordination *of neighboring base stations* • Coexistence control channels synchronization *using* synchronized time-slots • Frame synchronization (including Tx and Rx intervals) • Requesting and reporting measurements by different nodes • Selecting and advertising a new channel between networks • Implementing database for sharing information related to actual and intended future usage of the radio spectrum	
14.2	*Channel scanning and selection*	Normal
	• Dynamic channel selection • Adaptive channel selection • Scheduling for channel testing	
14.3	*Scanning and Discovery capabilities*	Normal
	• BS location discovery • Discovery of other users and testing their channels and discontinuing of operations if activity is detected • Obtain update information from data base	
14.4	*Coordination configuration capabilities*	Normal
	• Ability to set timing and threshold parameters	

Feature #15 – Layer-2 Routing		
Feature description	*Responsible for neighbor discovery, peer management, topology discovery, routing metrics estimation, and multicast tree route setup*	
Stimulus	*Data Transport Call*	
Response	*Passing routing information*	
Functionalities		**Priority**
15.1	*Neighbor and topology discovery*	Normal
	• Management frames for neighbor discovery • Management frames for topology discovery • Topology discovery protocol	
15.2	*Neighbor management*	Normal
	• Create neighbor table • Update neighbor table • Peer selection policy	
15.3	*Multicast tree route setup*	Normal
	• New management frames for tree construction protocol	
15.4	*Layer-2 routing protocol*	Normal
	• Programming routing metrics based on layer-2 parameters • New unicast and groupcast routing protocols. • New multihop management frames conveying reservation advertisement.	
15.5	*Cooperative retransmission policy*	Normal
	• New rules of packet parsing and relaying	

5 Requirements refinements

We revised the final list of requirements proposed in D212 for the FLAVIA system, by trying: i) to make more uniform the requirement abstraction level; ii) to distinguish between system primitives and additional programmable functionalities; iii) to add performance requirements.

The first revision goal has emerged because the heterogeneity of services and technologies considered for the FLAVIA functional analysis has often required significant abstractions, which in turns hided some specific functional details. For example, the implications of supporting random access schemes have been summarized into general requirements (such as implementing random backoff and carrier sense mechanisms), which in turns need more specific inputs (changing the contention window settings, the backoff extraction rules, the energy detection mechanism, etc.). In order to trade-off functional abstractions and requirement concreteness, we introduced two requirement levels, in terms of *abstract requirement goals* and *concrete functional/performance requirements*. Some of the requirements enumerated in the previous list have been mapped in the first category (and further expanded in concrete solutions), while some others have been mapped in the second one (and grouped in a common requirement goal).

The second revision has been based on the architecture sub-systems already pointed out for each elicited requirement in the previous list. We slightly updated the architecture break-through, by mainly distinguishing between FLAVIA primitives and FLAVIA programmable functionalities. The primitives involve both the basic commands for driving the PHY/hardware system (i.e. the wireless MAC processor primitives) and the control commands for extending the FLAVIA system functionalities and exposing customized interfaces (i.e. the FLAVIA control primitives). Conversely, the additional functionalities describe functions and services that can be loaded and dynamically linked on the system.

Finally, since this final requirement list has included specific implementation requirements, we were able to also specify some performance requirements emerged during the scenario revisions and early prototyping activities. The final list presented in the following table also defines the requirement priority (low *L*, normal *N* or high *H*) and the requirement type (functional *F* or performance *P* requirements).

Requirement goal		Priority	Type	ID	Requirement Description	Func./Serv.	WMP Primitive	Control Primitive
1	*Data frame forging*	*N*	*F*	1	*Encryption*	X	X	
		H	*F*	2	*Segmentation*	X		
2	*Changing Backoff rules*	*N*	*F*	3	Contention window selection		X	
				4	Set events for contention window update		X	
				5	Set events for backoff freezing / resuming		X	
				6	Inter-frame space configuration		X	
			P	7	Bound on configuration latency		X	
3	*Defining frame handshake*	*N*	*F*	8	Specification of reply frames to be sent without contention	X	X	
				9	Tuning of inter-frame spaces for regulating reply priorities		X	
4	*Support of collision avoidance*	*H*	*F*	10	Mechanisms for physical medium sensing		X	
				11	Mechanisms for virtual medium sensing	X		
			P	12	Bound on energy detection time		X	
5	*Transport Channel management*	*N*	*F*	13	Mapping transport channels into medium access rules	X		X
				14	Crete, modify and delete transport Channels			X
6	*Data Flow Classification*	*N*	*F*	15	Defining traffic classifiers	X		
				16	Modifying and dissecting MAC headers	X		
				17	Dissecting time critical MAC header fields		X	
7	*Control Frame Forging*	*H*	*F*	18	Defining customized control frames for different control operations	X		
				19	Mapping control frames to transport channels	X		X
				20	Dissecting control frame information	X		
8	*Efficient audio/video delivery*	*N*	*F*	21	Multi-flow traffic splitting	X		
				22	Intra- and inter-flow transport differentiation	X		X
				23	Scheduling policy	X		
				24	Access to user SLA	X		X

9	*Groupcast Management*	*N*	*F*	25	Groupcast acknowledgement policy	X		
				26	Multicast addressing	X		
10	*Performing Channel Reservations*	*N*	*F*	27	Compatibility with stations not involved in the reservation process	X		
				28	Admission logic	X		
11	*Support of polling*	*H*	*F*	29	Set up control channels for polling and feedback	X		X
				30	Inter-frame space configuration for managing access priorities		X	
12	*Collect Channel Statistics*	*H*	*F*	31	*RSSI/SNR/SNRI Measurements*		X	
				32	Busy/Idle slot detection		X	
				33	Estimate available bandwidth		X	
				34	Distance estimation from BS/AP	X	X	
13	*Collect Traffic Statistics*	*H*	*F*	35	Observing neighbor presence	X	X	
				36	Filtering traffic/ throughput statistics	X		
				37	Saving traffic statistics	X		
				38	Estimate traffic load	X	X	
14	*Queue Management*	*H*	*F*	39	Defining per-queue data structures			X
				40	Defining queuing policies	X		
				41	Associating queues to transport channels		X	X
15	*ACK Policy Management*	*H*	*F*	42	Controlling ACK generation or artificial dropping		X	
			F	43	ACK frame and handshake configuration	X	X	
			F	44	Associating ACK Policies to transport channels		X	X
			P	45	Bounding ACK processing time and timestamp accuracy	X	X	
16	*Flow Control Management*	*N*	*F*	46	Defining flow control policy	X		
				47	Configuring flow control parameters	X		X
				48	Associating flow control policies to transport channels			X
17	*Congestion Control Management*	*N*	*F*	49	Defining congestion feedback and Policy	X	X	
				50	Defining active queue management	X		
				51	Enabling/disenabling TCP congestion control	X		X
				52	Associating congestion policy to data transport channels			X
18		*H*	*F*	53	Beaconing	X	X	

	Cell search			54	Active Scanning	X	X	
				55	Passive Scanning	X		
				56	Probing	X	X	
				57	Channel synchronization		X	
			P	58	Converge physical loops to desired accuracy and within desired times		X	
19	*Cell tracking*	*N*	*F*	59	Scanning other cells while connected	X	X	
				60	Advanced parallel scanning (TDM, two radios..)	X	X	
20	*Point-to-Point Link management*	*N*	*F*	61	Scheduling or triggering hallo messages	X	X	
				62	Keeping multiple associations	X	X	
				63	Link set-up/tear-down	X		
21	*Neighbor discovery*	*N*	*F*	64	Create/Update Neighbor table	X		
				65	Peer selection	X		X
				66	Topology discovery protocol	X		
22	*Punishment functions*	*N*	*F*	67	Traffic shaping	X		
				68	Artificial disconnections	X	X	
				69	Changing flow priorities	X		X
				70	Jamming		X	
23	*Inter-cell coordination*	*N*	*F*	71	Coordination protocol	X		
				72	Dynamic time/frequency/antenna Assignment	X	X	
24	*Power saving support*	*H*	*F*	73	Switching the radio on/off		X	
				74	Scheduling activity intervals	X	X	
				75	Power tuning		X	
			P	76	Bound on radio adjustments latency		X	
25	*Per-frame PHY parameter tuning*	*H*	*F*	77	Carrier Sense Threshold tuning		X	
				78	Modulation and coding selection		X	
				79	Antenna selection		X	
26	*PHY MIMO Support*	*L*	*F*	80	Mode selection		X	
				81	Parallel streams setting	X	X	
				82	Opportunistic pre-coding	X	X	
				83	Per-carrier channel state information		X	
27	*MAC MIMO Support*	*L*	*F*	*84*	Mapping transport channels to MIMO modes	X	X	
				85	Virtual MIMO protocol	X		

			P	86	Nanosecond accuracy of receive/ transmit frame time stamping		X	
28	*Bandwidth Allocation*	*N*	*F*	87	Spectrum scanning		X	
				88	Spectrum utilization statistics	X		
				89	Protocols for cognitive allocation	X		
29	*Dynamic Bandwidth Aggregation/ Disaggregation*	*L*	*F*	90	Channel bonding		X	
				91	Changing the number of subcarriers used for OFDM modulations		X	
				92	Accessing different OFDM subcarrier groups as independent sub-channels		X	
30	*Partitioning Physical resources*	*N*	*F*	93	Reading HW/PHY available resources		X	X
				94	Defining virtual interfaces	X		X
				95	Scheduling virtual interfaces access to HW/PHY resources	X	X	
				96	Aggregating services to virtual interface	X		X
			P	97	No limitations on the number of virtual interfaces		X	
			P	98	Detecting violations between logical scheduling and actual resource usage	X	X	
31	*Extending System Functionalities*	*H*	*F*	99	Listing/adding/removing available functionalities			X
				100	Instantiating/starting/stopping available functionalities			X
				101	Linking multiple functionalities to a given service		X	X
				102	Exposing customized SAP to applications			X
				103	Resolving inter-service conflicts	X	X	X
32	*Inter-node Signaling*	*H*	*F*	104	Signaling protocols for BS to BS, MS to MS and BS to MS communication	X		
				105	Data forwarding for mobility support	X		
				106	Scheduling of report messages	X		X
33	*Self-configuration*	*L*	*F*	107	Environment estimation	X	X	
				108	Detection of system failures	X	X	
				109	Self-configuration policy	X		
34	*Handover Support*	*L*	*F*	110	Handover detection	X	X	
				111	Handover decision	X		
				112	Soft-handover support	X	X	
				113	Handover execution	X		X

35	*Layer 2 Routing*	*L*	*F*	114	Routing metric definition and evaluation	X	X	
				115	Unicast and groupcast routing protocols	X		
				116	Exposing Link Metrics to higher protocols	X		X

Table 2 List of Requirements

6 Conclusions

In this document we present the final list of FLAVIA system requirements, by starting from the revision of the scenarios considered at the beginning of the project activities and from the feedback provided by the initial architecture design and WP3 and WP4 prototyping activities.

The scenario revision has been carried out by identifying a limited set of FLAVIA system use cases, in which traditional scheduled-based and contention-based technologies have clear limitations and the FLAVIA system programmability may bring functional and performance benefits to different actors (namely, operators, manufacturers, users). By analyzing different approaches and procedural decisions required for adapting the FLAVIA system, we improved the understanding of the step by step system behavior and performance requirements.

Despite of the heterogeneity of the considered technologies, we were also able to propose some service and function generalizations (in terms of core common functionalities), which have been mapped into the final list of system requirements. We identified 35 main system requirements, which have been further decomposed into 116 specific inputs involving the basic system primitives (in terms of wireless MAC processor and control system primitives) and the add-on programmable functions.

Our revision will help for revising and validating the final FLAVIA architecture and for preparing the final demonstrations.

7 References

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