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Title: # A Flexible Protocol Stack for Multi-Mode Convergence in a Relay-based Radio Network Architecture

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A Flexible Protocol Stack for Multi-Mode Convergence in a Relay-based Radio Network Architecture

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***Abstract*— Wireless networks of next generation will satisfy the user demand for a ubiquitous mobile broadband access. Current research efforts are targeting therefore at the efficient realization of a flexible air-interface and network architecture. The plentitude of envisaged application scenarios and the complexity of communication technology seem to prohibit a "universal air-interface". Instead, many different solutions each customized to a specific communication environment are expected. Ideally, these solutions are modes of specific radio access technologies with a common functional as well as architectural basis. This paper presents the realization of relay-based wireless broadband networks benefiting from the convergence of multiple modes. A flexible air interface considers multi-mode capability in the user and control plane of communication protocols together with the related management. The modes are used in a complementary way, taking maximum benefit of the commonalities between them. The coexistence and cooperation between multiple modes enables the efficient realization of devices supporting multiple modes with the possibility to use available spectrum in a flexible way.**

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I. Introduction

Next generation wireless networks will strive to meet the consumer demand for a ubiquitous radio system that selects on its own from available transmission technologies the most adequate one. Wireless access is thereby provided from short-range to wide-area, with one single adaptive system for all envisaged radio environments. The radio system will efficiently adapt to multiple scenarios by using different modes, i.e., *Radio Access Technologies (RATs)*, of a common technology basis. The integrated projects WINNER and E^2R of the *6th Framework Research Funding Program (FP6)* of the European Union, belonging to the *Wireless World Research Initiative (WWI)* [1], focus on different aspects of the vision introduced above. Relay-based wireless mobile broadband systems [2], [3] as promising candidates for next generation networks are developed by WINNER. The WINNER system concept targets the complementary usage of multiple modes, preinstalled in the network elements. The envisaged adaptability of the different WINNER modes touches the aspect of reconfigurability. In contrast, reconfiguration management/functions, over-the-air download of software components and security aspects are the main focus of E^2R.

This paper concentrates on the concrete realization of a multi-mode capable relay-based wireless network and the convergence, i.e., coexistence and cooperation, between its modes. The multi-mode protocol reference model from [4] is therefore extended and refined in this paper in adding these aspects. The relay-based network architecture of the WINNER system concept which supports multiple modes is introduced in Section II. The separation of the protocol software into generic and specific parts as the basis for a multi-mode capable communication protocol is outlined in Section III and Section IV. The context of reconfigurability is part of the reference model but beyond the scope of this paper. Optimized transition between modes and coexistence/cooperation of different modes is realized with the help of a hierarchical management structure. In the following, the term "multi-mode" may be equivalently substituted by "multi-radio access technology", "multi-protocol" or "multi-system" and the term "layer" also implicates a "sub-layer".

II. Relay-based Next Generation Networks Supporting Multiple Modes

Relay-based wireless mobile broadband systems that provide a non-contiguous coverage in densely populated urban areas can serve as a prototypical example of potential 4G systems. Depending on the multi-mode capability of the network elements, different deployment scenarios can be characterized as shown in Figure 1. The network elements related to the air-interface of a relay-based system are namely the *User Terminal (UT)*, the *Relay Node (RN)* and the *Access Point (AP)*. RNs have the advantage of distributing the high capacity available at the AP into a larger region. RNs cost-efficiently extend the coverage of a single AP to areas originally not covered by this AP. The capacity of the fixed link between AP and RN can benefit from smart antenna techniques, spatial diversity and the exploitation of heavy shadowing through high spatial reuse. The network elements discussed here conform to the logical node architecture developed within WINNER and published in [5],[6].

For the sake of simplicity we limit in our illustrations of Figure 1 the available modes to two (mode 1 and 2). In the case of single-mode network elements the relay-based system has a classical multi-hop architecture as depicted in scenario (I.) of Figure 1. In scenario (II.), the RN uses simultaneously different modes of the air-interface for the RN-AP link and the UT-RN link respectively. These modes are preinstalled and used in a complementary way. Scenario (III.) introduces a multi-mode capable UT, which is able to connect to the AP and RN with different modes. Scenario (IV.) additionally introduces a multi-mode AP: The AP uses one mode for the relay link and a different mode for the link to the UT. In scenario (V.) all network elements are multi-mode capable enabling an efficient fulfillment of capacity and QoS requirements. This implies a joint *Radio Resource*

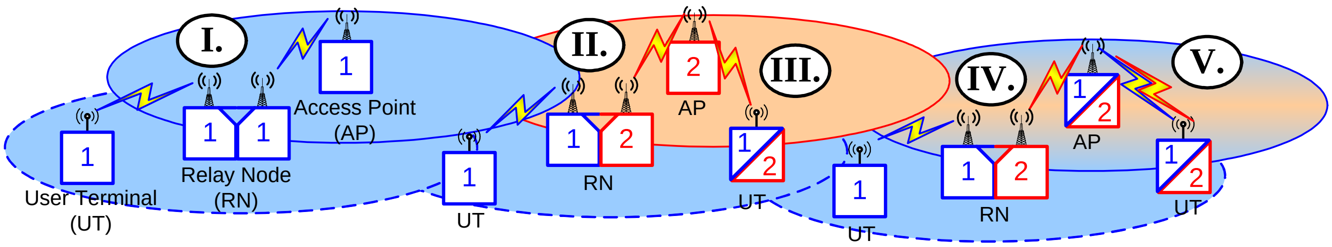


Figure 1. Deployment scenarios of relay-based 4G wireless networks characterized through the different usage of two modes (1 and 2). The coverage of the Access Points (solid elipses) is extended with the help of Relay Nodes (dashed elipses).

Management (RRM), inter-mode scheduling and self organization as outlined underneath. One example for scenario (V.) is the complementary usage of (i) a mode for a commercial relay-based system operating in licensed frequencies and (ii.) an "open spectrum mode" operating in unlicensed bands of free usage if available.

A reconfigurable network scenario of dynamically configurable network elements with over-the-air protocol (re-)configuration and software downloads leaves the scope of this paper but is nevertheless enabled through the multi-mode protocol reference model introduced below and in [4].

A. Related Work

Devices of a heterogeneous wireless infrastructure that use multiple modes (possibly simultaneously) in a complementary way are referred to as *composite radios* [7]. The composite radio concept implies pre-installed modes facilitating an optimized network utilization and QoS support. The dynamic identification/selection, installation and adaptation of the devices' modes to the communication environment and changing user demands are introduced at the example of reconfigurable baseband processing in [8] originating from the idea of *Software Defined Radios (SDRs)* [9]: The recent technological progress enables an extension of the key issues in research of SDR from the signal processing of the physical layer on the complete communication chain used for wireless communication [10].

III. Generic Protocol Stack for Efficient Multi-Mode Protocols

This section outlines the idea of a generic protocol stack for efficient realization of multi-mode capability in communication protocol software on conceptual as well as implementation level.

The basic idea of a generic protocol stack is that all communication protocols share much functional commonality, which can be exploited to build an efficient multi-mode capable wireless system. The term "generic" can be substituted in the following by "common" and "general". The aim is to gather these common parts in a toolbox of protocol commonalities referred to as generic protocol stack. Generic functions for example are specialized by parameters following particular requirements of the targeted mode, also referred to as RAT, and depicted in Figure 2. Depending on the supported number of modes more or less elements from the toolbox can be found in a single device. The targeted advantages of this concept are: code/resource sharing and protocol development acceleration through reusability, maintainability and runtime reconfigurability. As depicted in Figure 2, the generic protocol stack consists of different elements that can be identified as potential commonality in the context of communication protocols:

- Architecture and composition of a protocol stack
- Functions fulfilled by a layer that imply a certain behavior. A generic function can be parameterized to be used in a specific layer
- Data structures, i.e., protocol data units or information structures, used for communication between peer-entities of a layer.
- Protocol framework, i.e., common rules for communication, as for instance the structure of a *Medium Access Control (MAC)*-frame (sequence and duration of broadcast, downlink and uplink phase)
- Management of a layer and protocol stack

The commonalities form, together with mode specific parts, a system specific protocol stack. An efficient multi-mode capable stack is realized in adding management functions to take care of the composition and the parameterization of the mode-independent and the mode specific parts. This ensures modes convergence, which is introduced in the next section in taking up the composite radio paradigm of using modes in a complementary way. The introduction of additional reconfiguration management and functions leads to a dynamic reconfigurable protocol stack but leaves the scope of this paper.

A. Related Work on Generic Protocols

From the software engineering perspective, there are

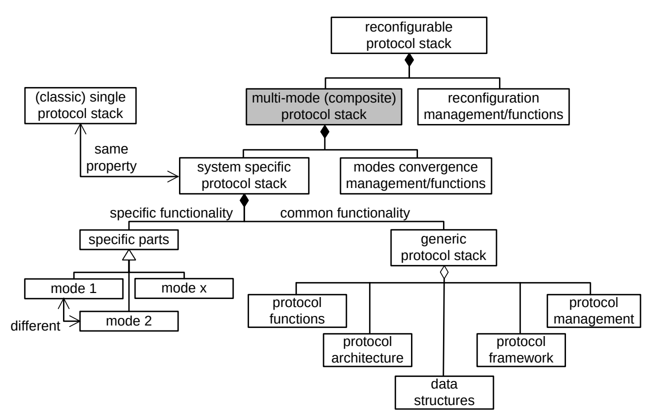


Figure 2. UML diagram of the generic protocol stack in the context of protocol multi-mode capability and reconfigurablility [4]

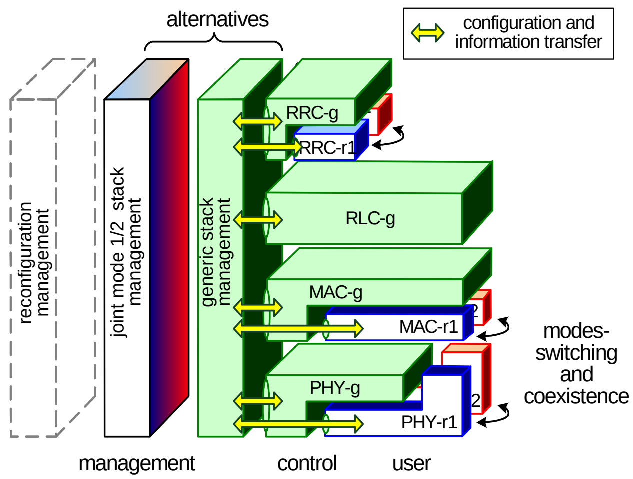


Figure 3. The Multi-mode protocol architecture facilitating switching between modes (inter-mode handover) and coexistence of modes (e.g. in relay nodes connecting different modes).

generally two possibilities for approaching the generic protocol stack: (i.) Parameterizable modules forming a toolbox of common protocol functions and/or (ii.) inheritance. The abstraction level of the identified protocol commonalities is one criterion to decide which advance to choose. The modular approach is introduced in [11], while the object-oriented approach is considered in [12]. The focus of this paper is on the combination of both approaches as outlined in Section IV.C. This combination promises to be adequate to fulfill all requirements of realizing a flexible protocol stack. Additionally, [13] takes up the idea of a generic protocol stack in focusing on a generic link layer for the cooperation of different access networks at the level of the data link layer. However, not only the link layer protocols but also adjacent layers' functions as for instance the control and management of the radio resources as well as mobility have to be considered in a multi-mode capable network.

IV. Multi-Mode Reference Model for Modes Convergence

A. *Definition: Modes Convergence*

A relay-based next generation radio access network as introduced above benefits from the multi-mode reference model proposed in [4], as it facilitates the coexistence and the cooperation of different modes in all network elements. This efficient integration of multiple such modes shall further be referred to as "Modes Convergence".

B. *Reference Model: Multi-Mode Protocol Architecture*

Figure 3 illustrates the architecture of a multi-mode protocol stack for a flexible air-interface. The layer-by-layer separation into specific and generic parts (where appropriate) enables a protocol stack for multiple modes in an efficient way: The separation is the result of a design process that is referred to as cross-stack optimization, which means the identification and grouping of common (generic) functions. The generic parts of a layer, marked green in Figure 3, can be identified on different levels, such as the *Physical (PHY)*, MAC and *Logical / Radio Link Control (LLC/RLC)* as shown in the figure. The common parts are reused in the different modes supported by the protocol stack and the composition of a layer out of generic and specific parts is exemplarily depicted in Figure 3.

The management and the joint handling of the protocol stack operating in different modes are performed by the stack management, also shown in Figure 3. When multiple modes are operated, this can be regarded as Cross-Stack Management and it is envisaged to be performed by a *Stack Modes Convergence Manager (Stack-MCM)* which controls the management functionality in the respective protocol layers (*N-Layer Modes Convergence Managers, (N)-MCM*) in a hierarchical manner. The introduced hierarchical management structure differs between the complete stack and single protocol layer. The counterpart of the Stack-MCM is the (N)-MCM which exists once in each layer as presented in this section.

These management-plane functions, responsible for ensuring the "Modes Convergence", thereby achieve the following

- Protocol convergence – integrating different modes in one protocol layer, also allowing coexistence and cooperation of modes
- Layer composition and parameterization – arranging functionalities and setting mode-specific parameters
- Data preservation and context transfer – to facilitate seamless transition / switching between modes

The introduced multi-mode protocol reference model facilitates the structuring of an arbitrary layer into generic and specific parts. In providing guidance for understanding this structuring, it marks up optimization potential in questioning the necessity of indicated differences. Compared to existing protocols standards, an increased protocol convergence is reached in this way enabling an efficient multi-mode capable protocol stack.

The reconfiguration-plane located beside the management-plane, see Figure 3, is not considered here in detail. Nevertheless, the Stack-MCM realizes the reconfiguration of the protocol stack from one mode to the other in providing services to the reconfiguration-plane. The reconfiguration-plane contains all functions related to reconfiguration management [14] as for instance the security aspects of reconfiguration and software download and the communication of the reconfiguration capabilities.

C. *Implementing a Dynamic Multi-Mode Protocol Stack*

The implementation of a dynamic multi-mode protocol stack is depicted in Figure 4. Fundamental, i.e. atomic, protocol functions are realized as generic (common to all modes) modules, which are parameterized corresponding to a specific mode. A segmentation and reassembly module is an example for such a generic function, realized as a module [11]. More complex and/or specific functionalities of a (sub)layer are provided in combining generic and specific parts, as for instance the concretion of a generic ARQ module to a mode-specific hybrid ARQ through inheritance. The scheduling between modes is a functionality which can be jointly fulfilled by generic and mode-specific modules. For further examples see Table 1. The modes' services of the

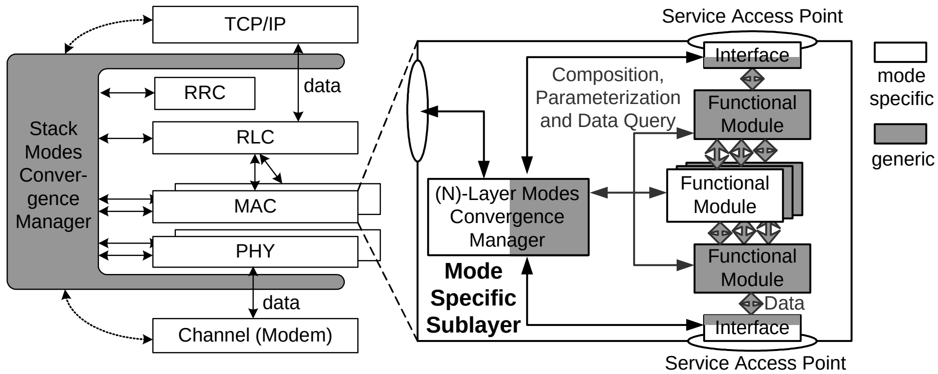


Figure 4. Composition, parameterization and switching between modes is done by Stack-MCM (on protocol level) and the (N)-MCM (on sublayer level). A mode specific sublayer is composed out of parameterizable modules realizing a generic of specific functionality. For example functions see Table 1.

layer are provided via *Service Access Points (SAPs).* Through this, layers can be configured for one mode at a time. Modes can also coexist temporarily or permanently. The specific SAPs of a layer are defined via the currently used mode or set of modes. This does not preclude the possibility that SAPs of different modes can be accessed by higher layer entities in a common way as visualized by L(N) SAP-g in Figure 5 a).

The composition and (re-)configuration of the layer is taken care of by a layer-internal instance, the (N)-Layer Modes Convergence Manager ((N)-MCM), which resides in the management plane. It is the layer's counterpart of the Stack-MCM as introduced above and illustrated in Figure 4. The (N)-MCM exists once per layer and enables that a (N)-layer provides multiple modes. It makes functionality available, of one mode or common to several modes. An instance of the (N)-MCM serves as a (re-)configuration handler in each layer of the air-interface protocols which parameters the generic part. In the case of a switching between modes, for instance reasoned by a vertical handover, the (N)-MCM is responsible for transferring data from the old mode to the new mode. The above mentioned context transfer of user data waiting in the queues of an ARQ module is supported by the (N)-MCM in questioning this data from the modules of a mode. The following examples show, how different elements of the protocol architecture can be implemented conforming to the reference model.

D. Application: Areas for Modes Convergence

Modes convergence can be differentiated into (i.) horizontal convergence – between "generic" and "specific" parts and (ii.) vertical convergence – the mapping of higher layer user data flows in the *Data Link Layer (DLL)* as known for instance from ATM. The focus in this work is on (i.), however, Figure 5 (a) - Case ② shows an example how the cooperation of modes can also facilitate (ii.).

1) Coexistence and Cooperation of Modes in Devices

Devices capable of (perhaps simultaneously) operating different modes at the same time are for instance multi-mode UTs, multi-mode APs or multi-mode RNs. Functions spanned across modes can be:

- Measuring availability and traffic characteristic of different modes as decision input for mode selection
- Switching between modes
  - Mode re-selection according to measurements and traffic requirements (see above)
  - Handovers between modes which can be network- or terminal initiated.
- Simultaneous operation of more than one mode
  - Bridging modes between hops in multi-mode relays
  - Routing of user data between modes in relays
  - Resource allocation in more than one mode
  - Scheduling of user data across modes, according to measurements and traffic requirements
  - Broadcasting of information with relevance across modes using a dedicated mode, e.g. to coordinate spectrum usage (see below)

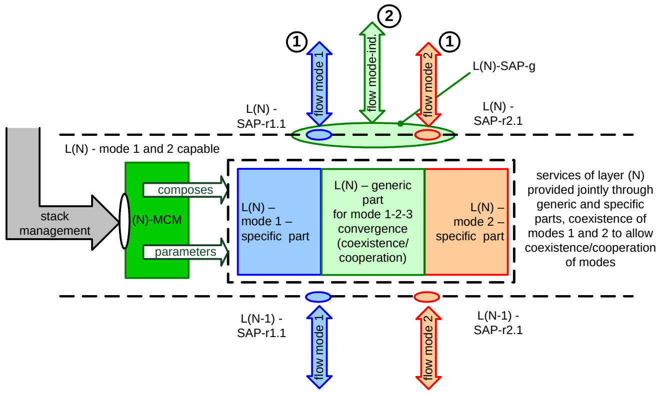
The convergence of modes in devices will be achieved through appropriate structuring of the functionality into mode-specific and mode-independent functions and the according management functionality to compose them and adapt to the designated mode, as already indicated above

2) Coexistence and Cooperation of Modes in Spectrum

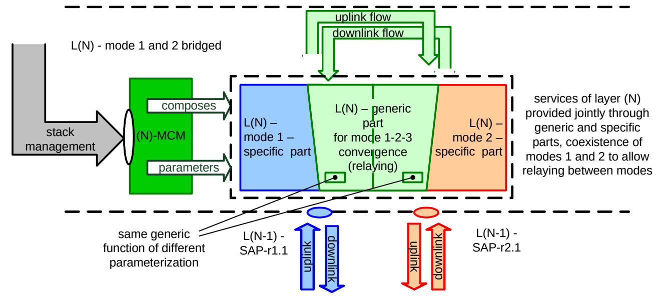
During the development and specification of next generation radio systems, the exact spectrum assigned for operation and the usage of this spectrum by the different envisaged modes has not been decided. Especially hierarchical spectrum sharing, i.e. secondary spectrum usage of frequencies originally licensed to a different (primary) radio system, promises to be a feasible solution for getting a sufficient amount of spectrum for future radio systems as introduced below. Thus, the case of devices sharing the same available radio spectrum while operating in different modes has to be considered.

The functions necessary to facilitate efficient coexistence of different modes sharing a common spectrum include:

- Measurement of spectrum utilization to ease spectrum sharing, i.e. detection of other devices (operating in other modes) using the same spectrum
- Signaling resource usage information between devices and across modes (over the air or through the core network)
- Joint Radio Resource Management: Coordination across neighboring APs/RNs operating in same/different modes



(a) Multi-mode operation. Either modes coexistence ① or modes cooperation ② is possible



(b) Realization of a multi-mode layer (N) relay. The common (generic) part enables the bridging between layer (N-1) traffic flows in different modes

Figure 5. Example configurations of a certain protocol layer or sublayer (N)

- Self organization: One mode of the envisaged communication system is able to autonomously decide about its radio resource allocations in taking the environment into account. This implies for instance the adequate selection of frequencies used for transmission or the routing of user data packets.

Figure 5 a) and b) define the general structure of a protocol layer conforming to the reference model from [4].

3) Example 1: Multi-Mode Layer-(N)

Figure 5 (a) shows that the (N)-MCM parameters the layer (the set of common and specific functions inside the dashed box) so that simultaneous operation in mode 1 and mode 2 is enabled. We distinguish two ways of operation which we call *modes coexistence* (①) and *modes cooperation* (②). In the first case, the layer can be regarded as "polymorphic", i.e., it can provide services of two (or more) different modes towards higher layers and use services of two (or more) different modes provided by lower layers. In the second case, the layer supports the cooperation of different modes, because it is able to provide mode-independent services towards higher layers, while using services of two (or more) modes provided by lower layers.

4) Example 2: Multi-Mode Relay

This second example in Figure 5 (b) shows how a multi-mode relay is formed. The different behavior of the layer as compared to Example 1 is achieved through different configuration/parameterization by the (N)-MCM. In this case, the layer bridges mode 1 and mode 2 and does not provide services towards higher layers. This way, a (heterogeneous) relay connecting two different air-interface modes can be efficiently implemented, because the functionality in the common part provides an inherent interface for the back-to-back interconnection of the different modes.

E. Generic Protocol Functions of a Relay-based Data Link Layer (DLL)

The architecture of most modern communication protocols cannot be entirely forced into the classical layered architecture of the ISO/OSI reference model. Though belonging to the DLL as specified in the ISO/OSI reference model, many protocol functions can be found in multiple layers of today's protocol stacks. Table 1 therefore introduces under "I." a characterization of protocol functions in identifying architectural elements and protocol layers where they are used. An ARQ module, optimized in its parameterization for the expected link quality is an example for a generic function as depicted in Figure 5 (b). The reliability of the wireless link determines the optimal packet segmentation size. In case of an ARQ-based "hop-by-hop" error correction the fixed high capacity link between AP-RN has a different quality than the link from the RN to the individual mobile UT, which is reflected in the parameters of the corresponding ARQ module for the respective link.

F. Identification of Commonalities in Radio Resource Management and Spectrum Sharing

The Spectrum sharing in next generation wireless networks considers the coexistence and cooperation between different modes and with other radio systems using the same frequency. Depending on the architecture of the wireless network, centralized or decentralized, different approaches to RRM and QoS support are necessary as depicted in Table 1, "II": In case of a centralized infrastructure the functions of joint RRM and coordination across neighboring cells are located in RNs and APs. The measurement of spectrum utilization is a generic function required in all scenarios to enable QoS support and efficient spectrum usage. It can be done with the help of generic measurement reports for broadcasting local spectrum utilization. These reports facilitate interference avoidance and coordination. The distributed coordination for supporting QoS on the basis of cooperation can be regarded as generic as it is required for coordination in horizontal as well as vertical spectrum sharing located in all devices of the network. The addressed sharing scenarios imply the consideration of regulatory constrains (policies favoring cooperation, etc.) in all devices of the network.

V. CONCLUSION

The efficient design and operation of network elements in a 4G radio access network supporting multiple modes of operation has been introduced. The design is based on a multi-mode protocol reference model proposed in a previous

Table 1. Two examples for dedicated familiy of protocol functions in the elements of a relay-based radio network and their corresponding layer

I. Multi-mode data link layer with relaying capability				II. Radio resource management and spectrum sharing			
protocol function	**architectural element**	**layer**	**generic**	**protocol function**	**architectural element**	**layer**	**generic**
E2E ARQ-protocol	UT/RN/AP	RLC	x	Medium access to radio resource	UT/RN/AP	MAC	
Hop-by-Hop Hybrid ARQ protocol	UT/RN/AP	RLC/MAC		Measurement of spectrum utilization	UT/RN/AP	PHY/MAC	x
Forward Error Correction, Cyclic Redundency Check	UT/RN/AP	PHY	x	Distributed coordination for QoS support[3,4]	UT/RN/AP[2]	RRM/MAC	x
Segmentation and concatenation	UT/RN/AP	MAC/RLC	x	Joint Radio Resource Management	RN/AP[1]	RRM	
Flow control	UT/RN/AP	RLC	x	Identification of unused spectrum[4]	UT/RN/AP[2]	RRM	
Scheduling between modes	UT/RN/AP	MAC	x	Release of spectrum for secondary usage[4]	UT/RN/AP[2]	RRM/MAC	
Reordering and discarding of PDUs	UT/RN/AP	MAC	x	Coordination across neigbouring RNs/APs	RN/AP[1]	RRM	
Switching between modes	UT/RN/AP	RLC	x	Integration of regulatory constrains (policies, etc)	UT/RN/AP	RRM	x
Handover between modes	UT/RN/AP	RRM/RLC	x	Consideration of user QoS requirements	UT/RN/AP	RRM	x
Bridging of multiple modes	RN	MAC/RLC	x	Measurement of link quality	UT/RN/AP	MAC/PHY	x

[1]in a centralized architecture, [2]in a decentralized architecture
[3]enabling horizontal spectrum sharing, [4]enabling vertical spectrum sharing

work and follows the paradigm of modes convergence. The convergence of the different modes to achieve their optimal cooperation and coexistence is an enabler for the efficient operation of multi-mode devices. A characterization of air-interface protocol functionalities as possible candidates for a generic, i.e., mode-independent, implementation is given. As a topic for further study remains the investigation of a possible complexity trade-off between parameterizable mode-independent functions and dedicated mode-specific functions.

Two exemplary functional areas have been taken for the characterization, which are −in the view of the authors− the areas that can benefit most from the cooperation and coexistence of modes. These two functional areas are: (i.) devices operating in more than one mode, alternating or in parallel − here the DLL and PHY layers will benefit from the exploitation of commonalities between modes and (ii.) devices operating in different modes by sharing a common spectrum − they can reduce mutual interference and thus enhance the overall network performance by sharing the spectrum in a coordinated way.

The presented reference model and design paradigm mark up optimization potential in the design process of next generation wireless broadband networks, leading to improved user perception of services and increased implementation efficiency.

ACKNOWLEDGEMENTS

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REFERENCES

[1] http://www.wireless-world-initiative.org, Nov. 2004.

[2] R. Pabst et al., “Relay-Based Deployment Concepts for Wireless and Mobile Broadband Radio,” in *IEEE Communications Magazine*, vol. 42, no. 9, Sep. 2004, pp. 80-89.

[3] N. Esseling, B. Walke and R. Pabst, “Performance Evaluation of a Fixed Relay Concept for Next Generation Wireless Systems,“ Book Chapter in *“Emerging Location Aware Broadband Wireless AdHoc Networks,“* Edited by R. Ganesh, S. Kota, K. Pahlavan, R. Agusti, Kluwer Academic Publishers, Boston USA, 2004.

[4] L. Berlemann, R. Pabst, M. Schinnenburg and B. Walke, “Reconfigurable Multi-Mode Protocol Reference Model Facilitating Modes Convergence,” in Proc. of *EW’05*, Nicosia Cyprus, Apr. 2005.

[5] N. Johansson, V. Sdralia and K.-E. Sunell, “Termination Issues of Retransmission Protocols”, in Proc. of *12th Wireless World Research Forum (WWRF)*, Toronto Canada, Nov. 2004.

[6] B. Walke, D. Schultz, G. Malmgren and E. Diaz, “Setting the Landscape”, *WWI Symposium 2004*, Brussels Belgium, Dec. 2004, available at http://www.ist-winner.org/

[7] P. Demestichas et al., “Management of Networks and Services in a Composite Radio Context,” in *IEEE Wireless Communications*, vol. 10, no. 4, Aug. 2003, pp. 44-51.

[8] M. Mehta et al., “Reconfigurable Terminals: An Overview of Architectural Solutions,” in *IEEE Communications Magazin*, vol. 39, no. 8, Aug. 2001, pp. 82–89.

[9] W. Tuttlebee, “Software Defined Radio: Enabling Technologies,” *Wiley Series in Software Radio*, ISBN 0470843187, 2002.

[10] J. Mitola, “The Software Radio Architecture,” in *IEEE Communications Magazine*, vol. 33, no. 5, May 1995, pp. 26-38.

[11] L. Berlemann, R. Pabst and B. Walke, “Multimode Communication Protocols Enabling Reconfigurable Radios,” in *EURASIP Journal in Wireless Communications and Networking, Special Issue “Reconfigurable Radio for Future Generation Wireless Systems”*, 2nd quarter 2005.

[12] M. Siebert and B. Walke, “Design of Generic and Adaptive Protocol Software (DGAPS),” in Proc. of *3Gwireless '01*, San Francisco USA, Jun. 2001.

[13] J. Sachs, “A Generic Link Layer for Future Generation Wireless Networking,“ in Proc. of *ICC’03*, Anchorage USA, May 2003.

[14] N. Alonistioti et al., “Reconfiguration Management Plane for the Support of Policy-based Network Reconfiguration,” in Proc. of *PIMRC’04*, Barcelona Spain, Sep. 2004.