A Multi-Radio Access Architecture for Ambient Networking

Johan Lundsjö[1], Ramón Agüero[2], Eftychia Alexandri[3], Fredrik Berggren[4], Catarina Cedervall[5], Konstantinos Dimou[6], Jens Gebert[7], Ralf Jennen[8], Ljupco Jorguseski[9], Reza Karimi[10], Francesco Meago[11], Haitao Tang[12], Riccardo Veronesi[13]

[1]Ericsson (Sweden), [2]University of Cantabria (Spain), [3]France Telecom R&D (France), [4]Royal Institute of Technology (Sweden), [5]TeliaSonera (Sweden), [6]Panasonic European Laboratories (Germany), [7]Alcatel SEL (Germany), [8] RWTH Aachen University (Germany), [9]TNO Telecom(The Netherlands), [10]Lucent(UK), [11]Siemens (Italy), [12]Nokia (Finland), [13] Consorzio Ferrara Ricerche, University of Ferrara (Italy)

Abstract—The Ambient Networks concept targets forthcoming dynamic communication environments; characterized by presence of a multitude of different wireless devices, network operators and business actors that can form instant inter-network agreements with each other. In this paper we propose an architecture, including the concepts of Multi-Radio Resource Management and a Generic Link Layer, for efficient use of heterogeneous access technologies in such emerging scenarios.

I. INTRODUCTION

TODAY there are many different radio access technologies (RATs) that differ in their support of data rates, mobility, coverage, quality of service, and possible business models. In the future, additional RATs will be available with other characteristics supporting new challenging networking scenarios, but most likely not replacing the existing technologies. The mixture of heterogeneous RATs will therefore be an important characteristic of future wireless communications.

There is plenty of prior research on how to combine different RATs, including a number of IST FP projects, e.g. BRAIN, MIND, DRiVE, WINE, ARROWS, MONASIDRE and EVEREST. However, this research has only tackled partial issues towards full network collaboration at the radio access level. The architecture presented in this paper is a result of the research on multi-radio access (MRA) within the Ambient Networks (AN) project [1]. It extends and generalises previous work to apply to any existing and future RATs. The architecture is novel in its provisioning of functionalities and mechanisms to support the AN vision of a dynamic environment with a multitude of different wireless devices, network operators and business actors that can form instant inter-network agreements with each other. These inter-network agreements can be the result of network collaboration or competition. The AN MRA proposes a consistent framework and a complete architecture that on one hand allows joint radio resource management across different RATs and on the other hand enables new business relationships among involved actors.

The paper is structured as follows: in Section II we give a brief overview of the Ambient Networks concept. Motivation, drivers and requirements for MRA are discussed in Section III. Section IV gives an overview of a proposed MRA architecture, followed by more specific details of its main components Multi-Radio Resource Management

(MRRM) and Generic Link Layer (GLL) in Sections V and VI respectively. Some critical architecture design options are summarized in Section VII. Finally Section VIII concludes the paper.

More thorough descriptions of the overall AN concept, the MRRM, and the GLL are provided in [2], [3] and[4].

II. THE AMBIENT NETWORKS CONCEPT

An *Ambient Network* can be seen as a new type of network-level "building block", existing above the level of individual devices or functions. It consists of a set of one or more nodes and/or devices, which share a common control plane, and implement well-defined external interfaces to Users or other ANs.

The core concept of the AN architecture is illustrated at its highest level in Figure 1. Networks include a flexible set of control plane functions, which together comprise the *Ambient Control Space (ACS)*, including the multi-radio access functions that are the main focus of this paper. The underlying data transfer and other user plane capabilities of the existing or new networks are accessed and controlled through an *Ambient Resource Interface (ARI)*. Together, they expose an *Ambient Service Interface (ASI)* to upper layer services and applications running within the network. Inter-network cooperation between different ACSs is mediated through an integrated set of protocols at the *Ambient Network Interface (ANI)*.

A basic mechanism of the AN concept is the dynamic and instant *composition* of networks without the need for pre-configuration or offline negotiation between network operators. Composition between ANs, which takes place over the ANI, enables the usage of resources without the need for long-term subscriptions, optimizes the delivery path and allows operators to flexibly integrate network technologies.
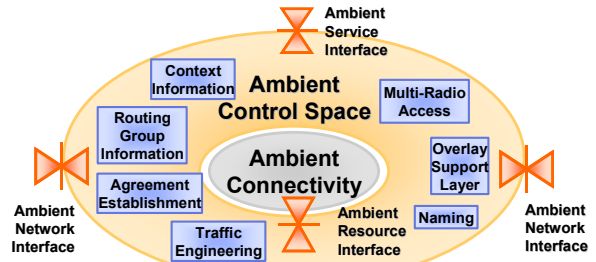

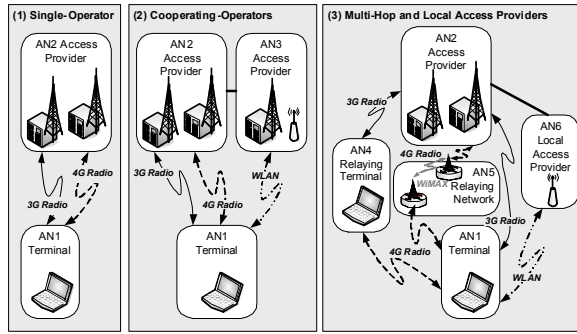Figure 1: Logical view of an Ambient Network

Figure 2: Three scenario examples

III. MULTI-RADIO ACCESS; MOTIVATION, CONCEPTS AND EXAMPLE SCENARIOS

A. Motivation for the MRA Architecture

Drivers for new MRA functionality can be identified from the perspective of end users, providers and regulators.
Users and providers have a common interest when it comes to flexible use of different types of wireless accesses, including selection of a "best" type of access, both from a user point of view (e.g. low cost versus high performance) as well as from a provider's perspective (e.g. load sharing). This calls for the capability of overall management of network resources of multiple network operators supporting required service provisioning. Users will expect service continuity when moving between accesses, sometimes (depending on application) implying the capability of lossless and fast handover between different Radio Accesses (RAs). The term RA is here used to refer to uncoupled radio channels, either across different RATs or within a single RAT (e.g. associated to different access providers). Furthermore, users will benefit from getting access to "any" network, requiring support for rapid establishment of roaming agreements (dynamic roaming) and efficient announcing strategies (of both user needs and provider offers).

Given the multitude of already existing, emerging and future RATs it should be in the providers' interest that there are means for efficient and relatively simple migration from present networks, to networks with more capabilities and support for more RATs.

Another common area of interest for users and providers is reduced cost, which may be enabled by new flexible deployment concepts [5].

The interests of regulators include means for increased competition on the market and efficient use of spectrum.

B. Multi-Radio Access Features and Concepts

The MRA architecture consists of two main components:

- *Multi Radio Resource Management (MRRM),* for joint management of radio resources and load sharing between the different RAs.

- *Generic Link Layer (GLL),* which provides unified link layer processing, offering a unified interface towards higher layers and an adaptation to the underlying RATs.
  These are built on previous research, such as [7][8][9] and [10][11] respectively, generalised and extended with

functionality for dynamic Ambient Networking. A main feature of the MRA architecture is resource sharing and dynamic agreements between ANs, including different access providers, through composition. Other novel features include efficient advertising, discovery and selection of RAs, including the possibility for a user to simultaneously communicate over multiple RAs, in parallel or sequentially. Furthermore, the MRA architecture includes support for multi-radio multi-hop communication, including moving and fixed relays.

C. Scenario Examples

The benefits and novelty of the MRA architecture can be exemplified by the three "cases" of AN configuration depicted in Figure 2. Each of these cases takes advantage of MRA, but with some differences in the involvement of the functionality. The cases could also be seen as describing the time aspect and thus reflect migration aspects towards AN.

In the first case a multi-radio access capable terminal (AN1) is connected to a single operator (AN2). Note that, in accordance with the AN philosophy, a terminal including an ACS is regarded as an AN of its own. This first case is to some extent already solved by state of the art solutions, e.g. national roaming between RAs belonging to one operator, and load management possibility for the specific combination of WCDMA-GSM [6]. The proposed MRA architecture adds generic resource allocation functionality that enables load management over all possible RAs, and instant mapping of data flows to different RAs.

The second case goes one step further by adding the possibility for information exchange between ANs belonging to different operators (AN2 and AN3), allowing terminals to access these separate ANs in a seamless manner. The level of information to be exchanged depends on the business relationship between the operators, ranging from full competitors to a cooperation relation.

The third case adds multi-hop and local access provider concepts. An operator (AN2) allows a user terminal (AN1) to establish connectivity in three additional ways: via another terminal acting as relay (AN4), via a set of fixed relay nodes (AN5), or through a local access point (provided by local AN6 access provider). Control signalling and user data may be separated on different RAs. An example could be that a local access provider (AN6), at a certain time instant, provides a direct user data connection to the terminal, whereas a cooperating wide area coverage access provider (AN2) handles the associated control signalling towards the terminal.

In all these cases the MRA architecture offers means for efficient resource sharing, within and between ANs.

D. Architecture Design Trade-Offs

There are many issues that affect MRA design choices and trade-offs have to be made. In the following a number of critical factors that have been considered in the MRA architecture design are exemplified.

The *time scale of operation* affects e.g. on what level in the protocol stack and how close to the radio interface certain functions are implemented. For example, the dynamic process of selecting the "best" RA may be based on

several metrics that vary over time. The time scale at which these metrics vary may differ a lot. At the extreme the RA selection may follow fast fading for one link (in the order of milliseconds), whereas if only system load is to be considered it may be enough to operate on a time-scale in the order of seconds. These aspects have been considered when proposing different levels of integration of RAs, and a functional split between MRRM and GLL.

Signalling overhead and *Signalling delay* have impact on the choice of which type of protocol a certain MRA function shall employ, at which level of the protocol stack it should be situated, and whether the protocol termination needs to be centralized or distributed in the network. There is naturally a dependency to the time scale of operation.

Deployment cost needs to be considered, e.g. when explicitly ensuring support for multi-hop networks and new deployment concepts.

Migration aspects need to be taken into account, allowing gradual introduction of MRA features and thereby evolve legacy networks into fully AN-compliant networks.

The *type and amount of MRA information that can be exchanged between different ANs* can be restricted for technical or non-technical reasons. For instance, a party (e.g. an operator) may not be willing to reveal certain information that may be relevant to a certain MRA function that is operated by another party.

IV. MULTI-RADIO ACCESS ARCHITECTURE OVERVIEW

A high-level view of the proposed MRA architecture is illustrated in Figure 3, showing functional blocks in a layered model, including user plane data flow (solid lines) and MRA (MRRM and GLL) signalling (dashed lines) through the layers. Arrows indicate control interfaces between different functional blocks, carrying information exchange and control commands e.g. for configuration or for measurement data retrieval. Note that only one communicating peer (network or terminal) is depicted. For the single-hop case the model can simply be mirrored at the other end.

The GLL is introduced on top of, and is partly replacing, the RA specific parts of the link layer. The toolbox of link layer functions within the GLL provides a unified interface towards upper layers (IP and above) in the user plane and provides adaptation towards the underlying (remaining RAT specific) link layers.

The MRRM functions are built upon, or mapped onto the network intrinsic RRM functions, which belong to the underlying RA and are therefore not within the explicit scope of the AN MRA. Two possibilities are illustrated for how MRRM signalling is conveyed between communicating entities, either over IP or directly mapped onto the GLL. Finally, the figure illustrates information exchange between MRRM, GLL and other ACS functions, here exemplified by mobility control and connectivity control.

The model suggests a functional split between MRRM and the GLL based on the MRA design trade-offs described in Section III.D. In general the GLL encompasses functions that are located close to the user plane of a data flow and/or need to operate on a relatively fine time scale. One example

is the RA selection for which a hierarchical distribution of functionality between MRRM and GLL is proposed, where the GLL dynamically handles the mapping of data flows to any of the RAs selected by MRRM. Another example is that GLL provides and reuses context information that is transferred between GLL entities at RA reselection for seamless access switching. The type of context information depends on the scenario, e.g. depending on the types of RAs and if they are located within the same or different ANs.

V. MULTI-RADIO RESOURCE MANAGEMENT

A. MRRM Functionality

Triggered by events such as session arrivals, mobility and resource optimisation, MRRM operates at system, session and flow level. At the *system level*, MRRM performs e.g. spectrum, load and congestion control. At the *session level*, MRRM coordinates decisions on different associated flows. At the *flow level*, MRRM establishes and maintains RAs that are possibly constituted of parallel multi-hop routes.

Two main types of MRRM functions can be distinguished. The *RA coordination functions* are generic MRRM functions providing coordination abilities that span over the available RAs. The *Network complementing RRM functions* provide missing, or complement inadequate, RRM functions to an underlying RAT such as admission control, congestion control etc. They are also responsible for providing a generic interface to the RA coordination functions through adaptation towards the Network-intrinsic RRM functions. In the remainder of this section we concentrate on the RA coordination functions.

The following definitions will facilitate the description:

- *MRRM Detected Set (MRRM DS)* is the set of all RAs that have been detected by MRRM through e.g. scanning or reception of RA advertisements.

- *MRRM Candidate Set (MRRM CS)* is the set of RAs that are candidates to be assigned by MRRM to a given data flow; it is always a flow-specific subset of the MRRM DS.

- *MRRM Active Set (MRRM AS)* is the set of RAs assigned by MRRM to a given data flow at a given time, and is always a subset of the MRRM CS.

- *GLL Active Set (GLL AS)* is the set of RAs assigned to a given GLL entity by MRRM to serve a given data flow at a given time; it is always a subset of the MRRM AS

Information included in each set may cover RA identity, capabilities, related measurements, access costs etc. The set definitions are valid in single-hop as well as multi-hop cases, combining multiple RAs sequentially (multi-hop) and/or in parallel. For scalability reasons, and as a possible result of composition, the different sets are defined recursively: e.g. an MRRM entity may expose an MRRM AS as a single RA, hiding its inner complexity.

RA Advertising informs about the presence of a network or its capabilities to provide a given service possibly in a business oriented fashion (with associated costs). For example, proxy advertisements could be sent on behalf of other access providers or network nodes.
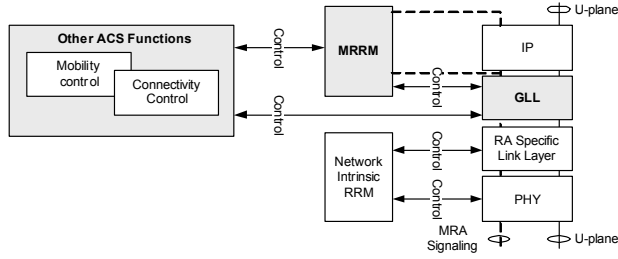
Figure 3: High-level MRA functional layer architecture

The *RA Discovery* function may use the RA Advertisements to identify and monitor candidate RAs and routes for specific flows. Thereby it establishes and maintains the MRRM DS and MRRM CS.

The *RA Selection* function selects the appropriate RAs for a given flow, thereby establishing the MRRM AS and the respective GLL AS. The first step of a RA Selection process is the *RA Evaluation* wherein several parameters may be considered, including signal quality and strength, end-user QoS needs, end-user cost-capacity performance, multi-operator network capacity, RA capabilities, RA status, RA availability, user and provider preferences and policies, and operator revenues in single/multi-operator scenarios. The evaluation is then followed by an *RA Admission* decision, ensuring that already established QoS agreements are protected.

MRRM Negotiation includes negotiation of MRRM roles during composition, and exchange of relevant information during MRRM operation, through various forms of information exchange.

At the system level, *Overall Resource Management* keeps a global control of network resources and protects established QoS agreements proactively within an AN and in coordination with other ANs. Means for this include load sharing, excess QoS elimination, QoS downgrading, flow/session dropping and dynamic spectrum control within or between RAs.

B. MRRM Distribution

MRRM functionality may be distributed within and across ANs in various ways. This will affect the type and amount of information that can be exchanged, and thus the possible degree of coordination, which in turn relates to the business models implied by the AN MRA cases. Flexibility is provided by the capability of MRRM entities to negotiate their respective roles towards each other.

Centralized MRRM control is likely to be beneficial in any network composed by a number of ANs belonging to a same administrative entity e.g. a personal area network (PAN). Another example is a centralized MRRM entity acting as an access broker, delivering commands or policies between ANs, or simply handling exchange of limited information such as availability of RAs.

Distributed solutions could be used in large networks for scalability reasons, or when a central coordination is simply not desirable due to the fact that the involved administrative entities pursue different strategies or don't trust each other. Scenarios characterized by a large number of small networks without a-priori relations are believed to put high requirements on the negotiation of MRRM roles.
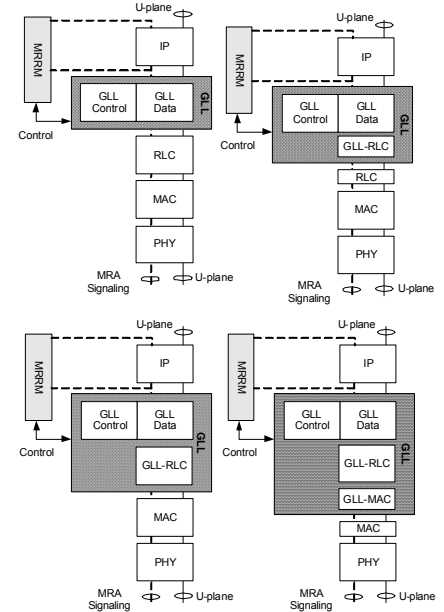

Figure 4: Four levels of GLL integration

VI. GENERIC LINK LAYER

Conceptually, the GLL consists of a toolbox of functionalities, which provides a unified interface to higher layers and facilitates efficient link-layer inter-working among multiple, possibly diverse, RAs. Along with the generic toolbox, the proposed GLL enables two novel applications. The first of these, named *Multi-Radio Transmission Diversity (MRTD)*, implies the sequential or parallel use of multiple RAs for the transmission of a traffic flow. The second, termed *Multi-Radio Multi-Hop Networking (MRMH)*, implies potential link layer support for multiple RAs along each wireless connection over a multi-hop communication route.

A. GLL Toolbox

The GLL has been defined as a toolbox of functions, making it possible to construct several alternative or complementing GLL solutions depending on design trade-offs. Figure 4 shows four different levels of GLL integration that have been defined. A major factor determining these levels has been the possible time scale of operation. The further down the GLL extends in the link layer, the finer the time scale of operation can be. For instance, the lower right case where GLL is integrated all the way down to the MAC level allows for dynamic scheduling onto different RAs on a per-MAC PDU basis. These different levels offer a migration strategy.

The model separates the GLL into the functional blocks GLL-C (control), GLL-D (data), GLL-RLC and GLL-MAC.

GLL-C contains functions for the link layer configuration and the interaction with MRRM, including *Access Selection Control*, *Resource Monitoring and Performance Monitoring* functions. Furthermore, it provides information on the QoS and the demands of different traffic flows. GLL-C negotiates with MRRM the GLL AS, within which GLL may autonomously perform RA selection. In addition, GLL supports *mobility management* functions and facilitates *context transfer* (GLL-D) and *security management* (GLL-

D, GLL-RLC).

The GLL functionality for support of MRTD and MRMH include *Access Scheduling* (GLL-D, GLL-MAC), *Buffer Management* (GLL-D), *Error and Flow Control*, *Segmentation* and *Reassembly* (GLL-RLC).

B. Multi-Radio Transmission Diversity

Based on a novel extension of the various transmission diversity mechanisms applied in legacy systems, MRTD may be broadly defined as the dynamic selection of multiple RAs for the transmission of a user's data.

MRTD can be performed at different protocol levels (MAC or IP level), with support of different RA re-selection rates. In addition, multiple RAs can be used for parallel (simultaneous) or switched (sequential) transmission of a traffic flow. Different MRTD schemes can also be combined. Typically, different RAs integrated in a common node can apply MAC level MRTD, which enables high RA re-selection rates by exploiting instantaneous feedback from radio link quality. However, this would require sharing detailed control information between the two ANs, which may not be possible or desirable for all business models implied by e.g. scenarios 2) and 3) described in Section III.C. In these situations IP level integration would probably be the preferred alternative.

C. Multi-Radio Multi-Hop

A potential feature of the GLL is *Multi-Hop ARQ* spanning over the complete multi-hop route, which may be described in terms of a two-stage error recovery process. The principle is that an intermediate relay node responds with an acknowledgement to the previous node when a data packet has been successfully received, thereby turning into a passive ARQ state. However, the previous node (and all nodes along the route) will not delete the transmitted data from its ARQ buffer until reception of a final acknowledgement from the final receiver. Associated functions include *Adaptation to different RATs* on different hops to handle different segmentation sizes per hop, and *flow control* and *priority based queuing* along the route.

MRMH can be combined with MRTD. Henceforth two route selection mechanisms can be identified, those that address the problem within the route (i.e. at the relay nodes) and those that address it from the edge-nodes of the network (i.e. infrastructure nodes or user terminals).

VII. ARCHITECTURE DESIGN OPTIONS

The flexibility of the proposed MRA architecture implies that many design choices have to be made for the implementation. Critical options, where the trade-offs discussed in section III.D have fundamental implications, include:

- Centralized versus distributed MRRM coordination between multiple ANs, as discussed in Section V.B.

- MRRM signalling carried by IP or directly mapped onto GLL, as indicated in Section IV.

- MRTD on IP packet level versus MAC PDU level, as discussed in Section VI.B

- Multi-radio multi-hop with or without explicit support from MRRM and/or GLL as discussed in Sections V and VI.C respectively.

Note that choices do not necessarily need to be strict, i.e. combinations of alternatives may very well exist in the same implementation. Feasibility and performance evaluations of various options are currently being evaluated.

VIII. CONCLUSION

We have presented a Multi-Radio Access architecture, supporting the vision of a dynamic environment with a multitude of different wireless devices, network operators and business actors that can form instant inter-network agreements with each other. The main components of the architecture are Multi-Radio Resource Management, providing joint management of radio resources, and the Generic Link Layer, which offers a unified interface towards higher layers and an adaptation to the underlying accesses. We have discussed the various features proposed, along with scenarios, requirements and design options.

Feasibility and performance of the proposed architecture and its features are currently under study and will be presented in subsequent publications.

REFERENCES

[1] WWI Ambient Networks, http://www.ambient-networks.org
[2] Niebert, N., Flinck, H. Hancock, R. Karl, H. Prehofer, C. "Ambient Networks – Research for Communication Networks Beyond 3G"- IST Mobile and Wireless Communications Summit 2004
[3] G.P. Koudouridis, R. Agüero, E. Alexandri, J. Choque, K. Dimou, H.R. Karimi, H. Lederer, J. Sachs, R. Sigle. "Generic Link Layer Functionality for Multi-Radio Access Networks", IST Mobile and Wireless Communications Summit 2005
[4] F. Berggren, I. Karla, R. Litjens, P. Magnusson, F. Meago, R. Veronesi, H. Tang., "Multi-Radio Resource Management for Communication Networks Beyond 3G", VTC Fall 2005.
[5] R. Agüero et al "RRM Challenges for Non-Conventional and Low Cost Networks in Ambient Networks", submitted to WPMC 2005
[6] 3GPP TR 25.881 "Improvement of Radio Resource Management (RRM) across RNS and RNS/BSS".
[7] A. Furuskär, J. Zander, "Multiservice allocation for multiaccess wireless systems," IEEE Trans. Wireless Comm, vol. 4, no. 1, 2005.
[8] A. Tölli, P. Hakalin,, H. Holma, "Performance of common radio resource management (CRRM)," IEEE ICC 2002.
[9] F. Malvasi et al., Traffic control algorithms for a multi access network scenario comprising GPRS and UMTS," VTC Spring 2003.
[10] J.Sachs, "A Generic Link Layer for Future Generation Wireless Networking,", IEEE ICC'03, May 2003.
[11] M.Siebert, B.Walke, "Design of Generic and Adaptive Protocol Software (DGAPS)," Third Generation Wireless and Beyond 2001 (3Gwireless '01)