Validation of the Ambient Networks System Architecture

Aurelian Bria, Jan Markendahl[1] , Rene Rembarz[2] , Petteri Pöyhönen[3], Csaba Simon[4], Marco Miozzo[5], Nadeem Akhtar[6], Ralf Jennen[7]

Abstract— The Ambient Networks project develops a complete and coherent solution for control architectures in future networks. In particular, the concept of Ambient Control Space has been proposed to support a technology–agnostic, modular and dynamic control plane. The second phase of the project (2006–2007) has an increased focus on validation, where two complementary tracks are being followed: proof–of–concept prototyping and performance evaluation through simulations. The prototype modules, focusing on requirement engineering, were validated during the process of integrating them into a common control space prototype, which was later used to build the demonstration setups. The system performance evaluation through simulations deals with aspects such as capacity utilization, reachability, cost and performance trade–offs and also provides evidence that the additional AN features (e.g., composition) do not introduce excessive signaling overhead. We target different composition aspects, advertising & discovery, negotiation of composition agreements and their interaction with multi–radio access and mobility control. Our validation approach is based on several use cases.

Index Terms— Ambient Networks, Multi–access, Multi–operator, Multi–service, Heterogeneous Networks, Network Composition.

I. INTRODUCTION

In the Ambient Networks vision "any" user will be able to connect to "any" network. This will increase the dynamics of interactions between different kinds of networks and between user devices and networks. In addition, the business dynamics will increase with a multitude of service and network providers and with an increasing number of business relations between market actors. The Ambient Networks (AN) project [1] aims to achieve this functionality for network co–operation in a technically simple manner, in order to promote its widespread adoption.

Ambient Networks will enable new business opportunities for existing mobile operators as well as for new actors in the mobile and wireless communications market. New forms of co–operation between providers can also be envisaged in order to provide anywhere and anytime connectivity for the end–users which have the following characteristics and benefits:

- Co–operating network providers can reduce cost for deployment of "own" networks, implying larger flexibility in investments and hence reduced risk.
- Users can choose freely from many providers of services and networks
- Existing market players will "get access" to all potential users
- Market entrants will experience low entry barriers
- Small scale businesses can act as service and/or network providers

The AN project defines an architecture [2], new functionalities, interfaces, and a framework for network cooperation. This framework for dynamic cooperation between both different kinds of networks as well as between business entities is called *network composition*. The terms and conditions of the technical and commercial cooperation can be negotiated on the fly and described by a Composition Agreements (CA). Composition will provide a unified framework over which dynamic cooperation between heterogeneous network providers, a multitude of service providers, and 'third parties' such as clearing houses and aggregators is established.

The main goal of the work presented in this paper is to verify that the Ambient Networks functionalities operate as expected and that the main objectives are achieved (i.e. better overall capacity utilization is achieved, improved reachability and reliability for users can be guaranteed, end–user cost/performance ratio is improved). Additionally, we want to detect constraints on signaling inside of the Ambient Control Space (ACS) or through the different kinds of interfaces proposed by AN.

II. VALIDATION APPROACH

While the first two years of the project have focused on the development of novel concepts, the second phase of Ambient Networks (2006–2007) is increasing its focus on integrating and validating the results. In order to ensure consistency of the concept on a high and abstract level, a dedicated work group

[1] Royal Institute of Technology, {aurelian, jan.markendahl}@radio.kth.se
[2] Ericsson Research, rene.rembarz@ericsson.com
[3] Nokia Siemens Networks, petteri.poyhonen@nsn.com
[4] Technical University Budapest, simon@tmit.bme.hu
[5] Consorzio Ferrara Ricerche, mzzmrc@unife.it
[6] University of Surrey, N.Akhtar@surrey.ac.uk
[7] RWTH Aachen University, jen@comnets.rwth-aachen.de

integrated and refined the Ambient Networks concept and documents them in a System Description document [2].

Nevertheless, this System Description is far too detailed and complex to allow a feasible implementation of an Ambient Network prototype within the time and resource budget of a two year research project. Therefore, the project adopted a common storyline i.e., Joint Use Case (JUC) [3] which helped to narrow down the potentially broad range of functionality contained in the System Description and focus on the important, project-level aspects. With a clear picture of the functionality needed, the process of selection and prioritization was greatly facilitated. Once the functionalities were selected, an integration framework was adopted. This framework served as glue for all the software modules, enabling the creation of a truly integrated prototype. We use the prototype as a test bed, not only for isolated analysis of the novel AN concepts, but also the interaction among them within a complex Ambient Network environment.

The software modules implementing a specific functionality provides an in-depth look at selected concepts, while the development of an integrated prototype proves that all concepts developed in the project fit together and form an coherent and consistent solution. Although a high level of detail is foreseen for this activity, and the aim is to study the feasibility and scalability of the concepts, the scale will naturally be limited. Thus, further activities are targeting the system level evaluations, in order to assess performance aspects of Ambient Network on a larger scale.

A. *Integrated Prototype*

The project-wide integrated prototype [3] is a key result of the Ambient Networks project. All work groups in the project implement prototypes of the control functionality they are developing. Later, these individual components are combined into a common prototype of the control functions.

The Ambient Networks concept of the Plug-and-Play control space is a key enabler for this way of working. This concept implies that all control functionality is modular, and can be added at any given time when required and can also be removed when it is not needed anymore. For the prototype work, it was decided to base the work on the protocols and tools from the Web Services technology, which – among other features – enable the communication of different software components using the Simple Object Access Protocol (SOAP), regardless of the programming language they were written in or the operating system they are running on. A specialized registry completes the picture, as it allows the different control functions to conveniently locate other control functions in the network; this way, the only thing a control function needs to know is which other service it is looking for, the location is then dynamically provided by the ACS registry.

The implementation is carried out in a limited set of programming languages (Java, C, C++, Python) on standard PC hardware under FreeBSD. For a complete description of the prototype approach and platform – which is not the focus of this paper – the reader is referred to [3][4][5].

Once the control functions have successfully been integrated into a control space prototype, they are put into the context of real-world scenarios. In order to implement the novel and innovative aspects of the Joint Use Cases mentioned earlier, the storyline is mapped to the concrete set of control functions and the required interactions among them. After that, the required hardware setup for the realization of a scene of the Joint Use Case is determined and the control functions are instantiated on the nodes. Thanks to some complementing features, such as user front-ends and a graphical user interface (which visualizes the status of the Ambient Networks protocols), demonstrations which are exposed in the major conferences and events throughout Europe were set up. This allow us to show the usefulness and the feasibility of the concepts developed within the Ambient Networks project.

As a contribution to the validation activities in the project, the experiences and results obtained in the implantation and integration work is fed back to all other work groups, especially the to group coordinating the top-down design of the system.

B. *System Evaluation*

With a prototype implementation (e.g. on standard laptop PCs), it is possible to reach a sufficient level of detail to assess the feasibility of a particular concept, but it is difficult to assess e.g. how such functionality performs if tens or hundreds of nodes are involved. The System Evaluation group closes this gap and studies abstracted functionality on a large scale by means of different simulations. Even though the discussion, as well as the results, we show in this paper are about simulation activities, the AN project has a broader scope, as discussed above. However, the developed simulator does not target to be a full AN simulator with all interfaces and with all kinds of functionality.

The work is centered on a set of Evaluation Cases (ECs) [6], which are very much in line with the Joint Use Case for the prototyping work, but tailored to the requirements of the work. For each case the performance aspects of selected control functions are studied. The following chapters describe the evaluation cases and present selected results.

III. DESCRIPTION OF ECs

There are four evaluation cases targeting different AN functionalities and deployment scenarios. The general business environment assumes several competing operators, which may also cooperate for enabling better service. The first evaluation case deals with *advertising and discovery* of existing access networks. Although necessary, the associated overhead should not be too large or introduce a large penalty (e.g. decreased system capacity or too much power consumption). How large is the *penalty associated with inter-operator handovers* is the main topic of the second evaluation case. Too frequent handovers may lead to worse performance as the user is often disconnected, or, the network consumes too a high amount of resources for the user in question. The special case of mobile multimedia services is considered in the third EC, where the *handover time and signaling overhead* are estimated. The fourth EC deals with *scalability of the algorithms* for access selection under different business relationships among competing operators.

IV. Advertisement, Discovery and Handover in Multi-Provider Environments (EC1&2)

The solutions and concepts developed in Ambient Networks project aim to enable better overall capacity utilization, improved service availability and reliability for the users. In particular, the concept of *network composition* has been proposed to support dynamic and flexible business relationships between end users and service providers. Composition could allow a full integration among networks and users' mobile terminals, a feature that could be exploited by users to move across systems without any service interruptions. Prior to negotiation of Composition Agreements, there is an *advertisement phase* during which access providers inform potential customers about service offers. This is followed by a *network attachment* phase in which a secure communication channel is established between the two parties.

The benefits from use of AN technology must be achieved at a reasonable cost in terms of resources consumption, both in terms of network traffic load and mobile terminals battery consumption. In addition, latency due to AN messages, exchanged during the attachment processes, has to be evaluated in order to understand when seamless handover may be guaranteed. In order to evaluate the cost of signaling for composition establishment, a simulation-based study was carried out to address the following aspects:

- How will signaling load and delay increase with number of users and providers?
- How will signaling load and delay increase with the *greediness* of users?
- How large is the load of the business related signaling compared to the "useful" application data transferred during a user session?
- How latency due to attachment process will compromise seamless handover?

Here the term *greedy* refers to a user that acts in a *selfish* way by consuming a lot of network resources while investigating service offers from many providers and participating in complex negotiations spanning multiple rounds with many network providers. In contrast, a less greedy user would immediately accept the first received offer from a network provider.

The signaling load and delay were investigated by modeling a multi-provider network scenario. A simplified model of Ambient Networks was developed in the Network Simulator (ns2) using the Miracle library [7] (see Figure 1) which includes all the functionalities and protocols required to implement the advertisement, network attachment and composition procedures. In particular, besides the standard protocol stack, a number of Ambient Networks components were added: the GLL-FE (Generic Link Layer-Functional Entity), the MRRM-FE (Multi Radio Resource Management), the Composition-FE, the GTLP (Generic Transport Layer Protocol) and the Composition-GSLP (Generic Service Layer Protocol). A special bus was created inside each entity, either the mobile terminal (MT) or the access points (APs) for inter-FE communication. In addition, communication between FEs placed in different entities occurs through the GTLP (Generic Transport Layer Protocol) by means of GLTP messages that are sent via the standard protocol stack. This is achieved through the encapsulation of GTLP messages into IP packets. The GLL-FE is in charge of obtaining QoS indicators for both the MAC and the PHY layers. At the MT, for instance, these indicators are either obtained through the reception and the subsequent elaboration of the advertisements sent by the APs or from the collection of statistics, such as bit error rate and received power, during data transmission/reception. Quality indicators may be specifically related to the received power (Pow(ref) in the Figure 1) or be user defined (QoS(ref) in the Figure 1). These quality indicators are then passed to the MRRM-FE.

The MRRM-FE contains the Network Advertisement and Discovery FE (NAD-FE) and MRRM-specific execution logic. The role of the NAD-FE is to decode incoming advertisements as well as to put the advertisements to be sent by the MT in the right AN format. Both the NAD-FE and the MRRM-FE (or better its execution logic) are directly connected to the protocol stack. In particular, the execution logic of the MRRM is directly attached to the link layer (LL in Figure 1).

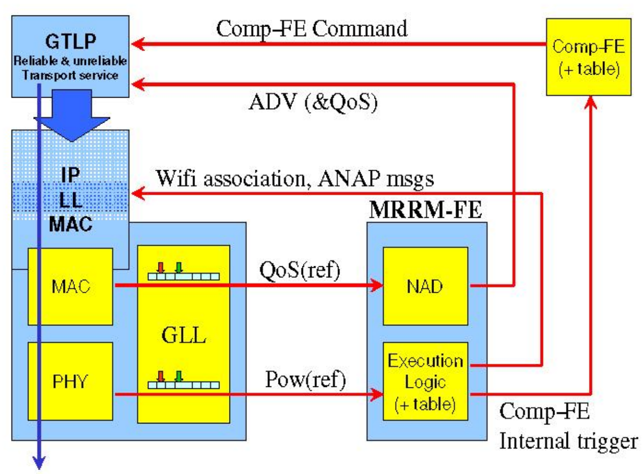

Figure 1. AN architecture and its implementation in the simulator

This is to handle network association procedures (such as Wi-Fi association messages) when IP connectivity still has to be established. In addition to that, link layer messages are required by the Ambient Network Attachment Procedures (ANAP), which are necessary to establish basic AN connectivity with a foreign network. The last component in the architecture is the Composition-FE, which is in charge of handling the composition procedures. In the following we first analyze signaling load due to advertisement, attachment and composition, followed by analysis of the effect of these procedures on handover performance.

A. *Signaling Load Analysis*

The signaling load analysis was performed for the scenario depicted in Figure 2. Only one network provider is shown for reasons of simplicity but the analysis included multi-provider cases. The AP represents an access provider which composes with Mobile Terminals (MTs) enabling the latter to establish application sessions with the media server (MS).

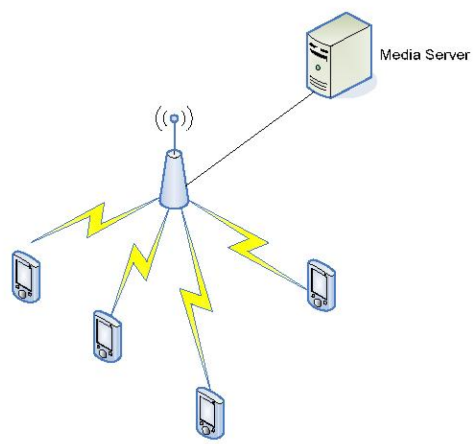

Figure 2. Signaling Simulation Scenario

First, the amount of signaling bits required for the attachment and composition related procedures is estimated, as given in the table below (assuming that WLAN is used). [6][11]

Table 1 Signaling load for different procedures

Signaling Phase	*Signaling Bits*
Network Attachment	13328
GANS Signaling Association	4587
CA Negotiation	(2q-1)*2999 + 1591
CA Validation	3182

Based on these estimates, the total signaling was calculated for a scenario where *n* users attempt to connect to an access network over a period of time. Each user undertakes a single round CA negotiation in parallel with M access networks, followed by a 128 kbit/s CBR session with the media server. The session duration is assumed to be exponentially distributed with a mean value of 5 minutes.

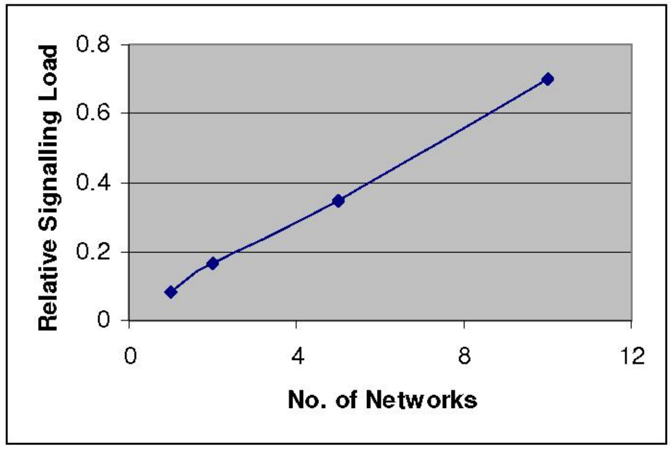

Figure 3. Relative signaling load for composition

Figure 3 shows the relative signaling load (the ratio of no. of signaling bits and no. of application data bits.) for various values of M. Note that although the load increases linearly with M, it is less than 1% of the data traffic generated during the application session even when the user negotiates with ten networks before selecting the one via which the media session is established.

The effect of greedy behavior on the part of user is illustrated in Figure 4. These results are obtained by varying the number of networks (*M*) and the number of negotiation rounds (*q*) while keeping their product fixed ($M \cdot q = 10$). One observation is that negotiating *less* with many networks consumes more resources than negotiating *more* with fewer networks. The reason is that attachment and other one-time signaling, as signaling for composition validation and realization, requires exchange of more bits than multiple negotiation rounds.

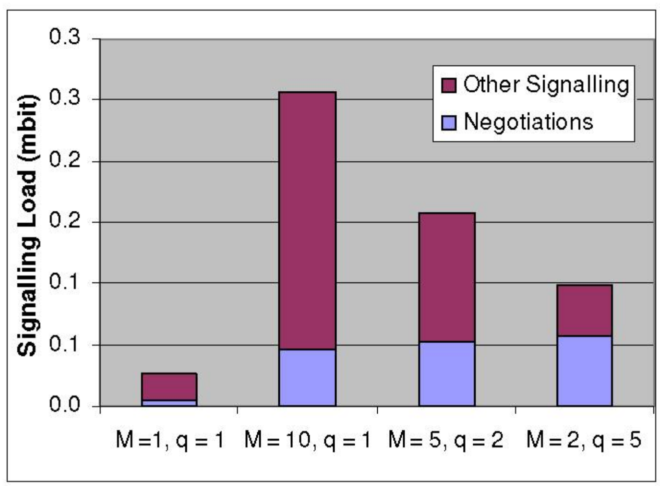

Figure 4. Effect of greediness on load

B. *Delay Analysis*

The scenario depicted in Figure 5 was considered. A (or a group of) mobile terminal(s) (MT) moves between two IEEE802.11b access points, AP1 and AP2 belonging to different operators. The movement is assumed to be linear and the speed constant (straight line connecting point A to point B in the figures). The MT is initially at point A and is connected with AP1. The data traffic, a streaming flow transmitted via UDP, gets to the MT through the downlink connection provided by AP1. As before, a Media Server (MS) is assumed to exist. This is placed somewhere in the Internet and has the role of providing the streaming traffic to the MT.

During the simulation the MT moves towards AP2 and has to change the attachment point from AP1 to AP2 in order to maintain media session with the MS. In case of multiple users, the movement is completely synchronized (i.e., all the users start movement at the same time and with the same direction and speed).

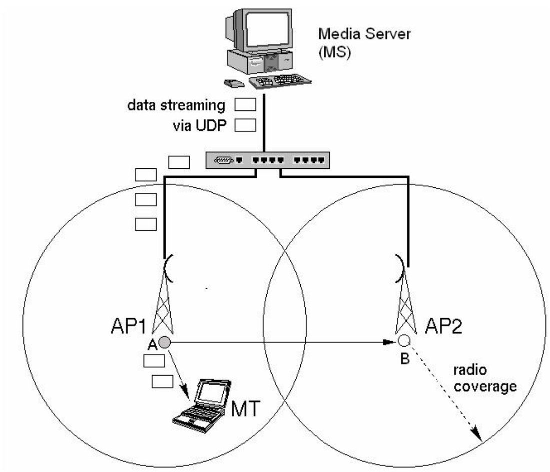

Figure 5. Delay Evaluation Scenario

Figure 6 shows the handover delay (in seconds) for streaming services with data rates of 7Kb/s and 14 Kb/s at user speed of 2 Km/h. Observe that when the number of users is small (smaller than four) the delay experienced at application layer is zero. A zero delay is measured here as the inter-packet transmission time is longer than the time required to performing the attachment procedure and subsequently changing the point of attachment from the first to the second access point (AP2). Hence, the application sees no delay in these cases. Further, as the number of users handing over at the same time increases, we observe that the delay increases. In our setting, after 8 users the delay is too high and therefore the handover cannot be any more regarded as seamless.

From Figure 6 we can draw two main conclusions. First of all the composition procedure enables a seamless handover between different operators/networks when the system load is low. As the system load (i.e., the number of users handing over at the same time) increases a seamless handover is no longer possible due to collisions at the MAC layer.

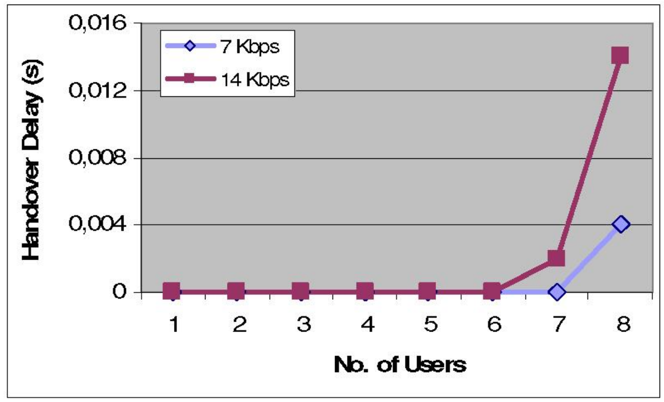

Figure 6 Handover delay for data rates of 7 and 14 Kb/s

As the system load (i.e., the number of users handing over at the same time) increases a seamless handover is no longer possible due to collisions at the MAC layer. With a 802.11b wireless technology the limit seems to be around eight users. Note also that this limit is deemed to decrease for an increasing data rate.

V. MULTI-HOP EXTENSIONS USING OVERLAYS (EC 3)

As the distance between mobile terminal (MT) and access point (AP) has a major impact on the available data rate this variation is further increased. Altogether mobile users will experience continuously changing radio conditions. Especially for applications with high data rate requirements such a situation is hard to handle. If the available data rate drops below a certain limit the service has to be interrupted. New upcoming services like Internet Protocol Television (IPTV) or Video on Demand (VoD) are a good example for such resource consuming applications. The streaming of video data needs massive download rates in the wireless network. Short performance degradations or connection interrupts can be handled by buffering data at the end device but longer phases of low radio link performance would force the service to stop.

Smart Caching makes use of it and pre-fetches e.g. video data at the edge of the backbone (in the Caching Media Port (CMP)). Here the data is stored until the terminal comes into service range of an access point. From there on as much as possible data is transferred while a connection exists. Compared to legacy streaming the amount of buffered data in the end device can be substantially increased by Smart Caching. The investigated deployment scenario is depicted in Figure 7 where a mobile terminal moves through an area covered by different access networks partially consisting of relay enhanced cells. In the upper part of the figure it can be seen that different Access Gateways (AG) and Caching Media Ports are responsible for different coverage areas or administrative domains, whereas the data stream comes from a Media Server outside of the Access Network AN.

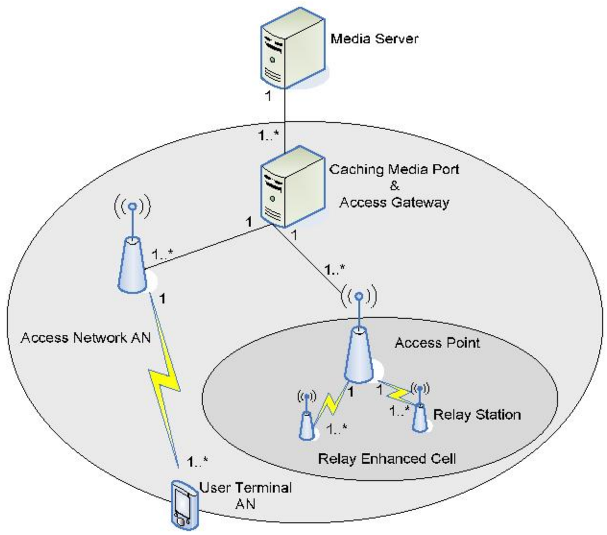

Figure 7 Evaluation Scenario for EC3

AN combines the idea of smart caches with the concepts of overlays in order to allow to include a cache into an overlay when needed. The overlay checks the QoS requirements of the multimedia session and translates them to access technology specific QoS requirements. As soon as those requirements cannot be fulfilled any longer the overlay has to take appropriate countermeasures or has to abort the media delivery in the worst case, namely that no connectivity is available at all. AN allows the overlay to create constraints with the help of HOLM which has to be considered by the used link.

AN enables the overlay to be notified by MRRM when the constraints are not met any longer. MRRM and NAD collect as much information as possible in order to support the overlay in the service delivery, explicitly in meeting the constraints. That is why the MRRM and NAD collaborate with the GLL in order to detect and attach to new links. This mechanism might already be useful in cases where only one radio technology is deployed but gains strength when multiple technologies are considered, because MRRM and GLL are able to hide the complexity of the underlying network from the overlay management. This study investigates the inter-working of the overlay management (SATO) with the constraint management (HOLM) as well as the link management (NAD/MRRM/GLL). The implemented protocol stack is shown in Figure 8. The offered traffic type follows Poisson process and the modeled radio access technology (RAT) follows the concepts proposed by the WINNER project [10]. For a multimedia session the most important parameters are the packet–and handover delay. Their values are given in Table 2, for both the situations when the Candidate Set (CS)[8] is assumed or not. Additionally to the impact of the users' sessions there is an influence on the required signaling traffic.

[8] Candidate Set is the set of access flows which are candidates for being assigned by MRRM to a given active bearer.

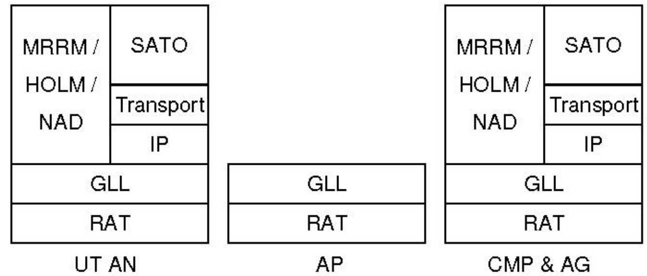

Figure 8 Protocol stack of the different nodes

Figure 9 presents the signaling overhead for different Link Going Down (*LGD*) triggers in dB and window sizes (*W*) in number of considered data packets. The windowing mechanism takes into account the *W* previously received data packets and creates a link going down event if the mean SINR value of those packets is below a certain threshold. The configuration of *W* by the MRRM obviously allows to adjust the sensitivity of the algorithm.

Table 2 Simulation results for different types of handover

Type of the handover	CS	Average packet delay, [*ms*] / Standard deviation [*ms*]	Average handover delay, [*ms*] / Standard deviation [*ms*]
AP to AP	Yes	0.72 / 0.0036	10.25/ 0.0017
AP to AP	No	0.72 / 0.0003	10.9737 / 0.0017
AP to RS	Yes	1.28 / 0.0007	15.22 / 0.0019
AP to RS	No	1.28 / 0.0007	17.17 / 0.0017
RS to RS	Yes	1.82 / 0.0005	20.28 / 0.0017
RS to RS	No	1.82 / 0.0005	23.39 / 0.0017

As can be seen from the shown values the size of this window has a dramatic influence on the signaling overhead. Therefore, from this study it can be stated that although the values for the packet– and handover delay range only in an interval of 0.72 and 1.82 *ms* the amount of the signaling overhead may vary up to the factor 14 depending on the

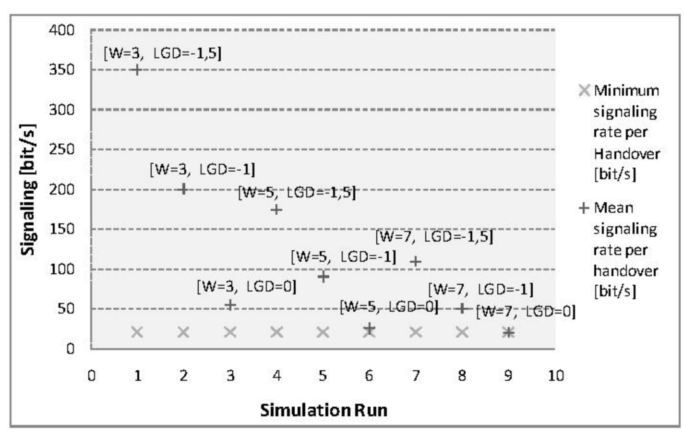

Figure 9 Signaling overhead for different window sizes and trigger levels.

configuration of the GLL trigger levels, e.g. for *W*=3 and a *LGD* threshold of 1,5*dB* the signaling overhead is 350 *bit/s* whereas the minimum signaling rate of 25 *bit/s* per handover is reached for *W*=7 and *LGD*=0 *dB*.

VI. DISTRIBUTED ACCESS EVALUATION AND SELECTION FOR HANDOVER DECISION MAKING (EC4)

This EC performs algorithm-centric simulations. Unlike other ECs, it does not consider protocol and messaging details, thus focus on how information validity and visibility scopes affect the functioning of distributed access evaluation and selection algorithm. The distributed algorithm is evaluated in a heterogeneous business environment where different kinds of agreements limit information visibility and scope [6][12]. Respectively, networking environment is heterogeneous including multiple Radio Access Technologies and business players like network providers, home operators and service providers.

The business players have both cooperative and competitive roles and two types of agreements are assumed. On one hand there are long term business agreements between providers (e.g. Service Level Agreements) and the agreements between users and operators (subscriptions). On the other hand, there are short or long term Composition Agreements between networks or between user devices and service or network providers. In this case the focus is on the business agreements although CA´s are established dynamically in order to enable the connectivity. It is important to note that a user may be connected to a network without having any business agreement with the operator of that network, see. Figure 10. In this case the user has business relations with service providers and the home network operator and these have business relations with operators providing the "visited" network.

The business agreements between providers can be vertical or horizontal. In Figure 10 vertical agreements can be between home network operator and candidates for visited networks (i.e. for roaming) or between service providers and network operators for providing the connectivity needed for service provisioning. Agreements between network operators enable load balancing and access in areas of non overlapping coverage as well as support for seamless handovers

EC4 is an extension of the Path Selection –MRRM Decision evaluation work represented in [8] and is studying how different strategies of a distributed access evaluation and selection ("HO decision making") algorithm performs and scales in a heterogeneous multi-access environments (multi-operator, multi-service and multi-RAT). The evaluated strategies are [6]:

Terminal centric – the final handover decision is made by terminal based on ordered access sets generated by terminal and network during the access evaluation and selection process.

Network centric – the final handover decision is made by network also based on ordered access sets generated by terminal and network during access evaluation and selection process.

Legacy - models "GSM like" handover decision logic where the measured signal strengths have an essential role compared to the other strategies and where the network makes the final decision.

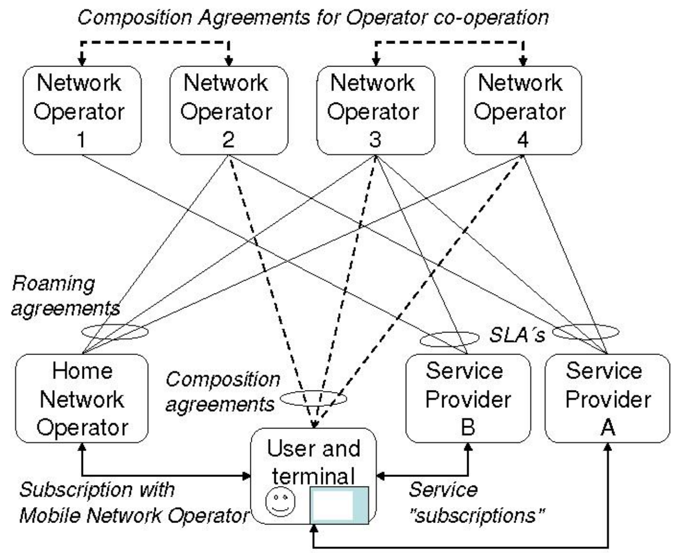

Figure 10 Business relations and agreements (solid lines) and composition agreements (dotted lines)

In our simulation model, four wide area coverage operators are assumed, two hotspot providers, three service providers and two home operators. Mobile terminals were not following any specific mobility pattern, thus random based mobility movement paths were used for 1000 MTs. The simulation time was 240s, during which 2400 measurements were done. The algorithm strategies, distributed access evaluation and selection algorithm, constraints, simulation model and configuration are further explained in [9].

A central piece in the description of the distributed HO decision making is the use of the constraint criteria. The constraint is basically various parameters from different network devices and functional entities (FEs) influencing the access evaluation and selection. The constraints affect the selection process sequentially and by structuring the constraint applying order can different results be achieved.

The main focus is to study how different types of constraints are constructed, where related condition information is available and in which order constraints are then applied. The modelled algorithm that is collecting condition information, constructing constraints and executing them is mostly based on [9]. There are three FEs that mainly are considered:

1. Multi-Radio Resource Management (MRRM)
2. Handover and Locator Management (HOLM)
3. Path Selection

This simulation study produced various results like connectivity and outage statistics, HO statistics and network utilization rates for different strategies. Only few results are presented herein and the detailed results can be found in [2]. Figure 11 illustrates the connection statistics for each algorithm strategy. The best connected state is achieved with the network centric algorithm, while the terminal centric algorithm is well following the network case. Legacy clearly has less number of connected mobile nodes.

The price for better connectivity through the network centric algorithm is higher number of HOs The better connected state of the non-legacy (the terminal and the network centric) algorithms also result better network utilization rates over the legacy strategy.

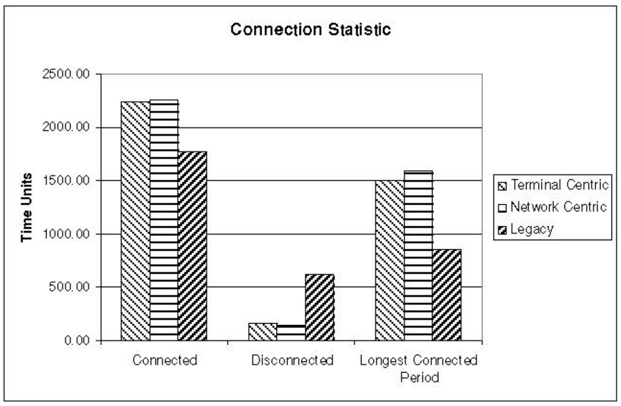

Figure 11 Connection Statistics

VII. CONCLUSIONS AND FUTURE WORK

The prototyping made possible a string of successful demonstrations proving that the idea of using one common control plane for the ambient networks is viable and is able to manage and control such a complex networking architecture. From the simulations, the main conclusion is that signaling load due to composition procedures is very low compared to user data, in the order of 1%, even when the amount of user data exchanged is small. To obtain a service, in a multi-provider environment, it makes more sense to negotiate *more* with a few networks as compared to negotiating *less* with several networks. The analysis was performed only in WLAN hotspot scenarios. Future work will consider UMTS networks as well. The current handover practices, also referred as the legacy strategy in the simulation studies, tend to rely on static and preconfigured information and business relationships. Therefore, this type of strategies does not result in the optimal access selection in a multi-operator and multi-service environment where relationships between business players are not static, but dynamic. Better network utilization implies better readiness of networks under heavy traffic conditions, potentially increasing the revenue of different business players, as network operators and service providers.

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EU DISCLAIMER

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