RRM Challenges for Non-Conventional and Low-Cost Networks in Ambient Networks

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Abstract— **This paper presents an overview of the Radio Resource Management (RRM) functionalities needed for Non-Conventional and Low-Cost Networks. These types of networks are characterized by increased cooperation between different types of networks and providers and they are believed to play a fundamental role for future wireless network networking. The paper describes three specific concepts, which latter is used to identify new RRM challenges. In addition, it identifies the relation between the RRM challenges and the Ambient Networks architecture and functionalities, in particular the multi-radio resource management functionality.[1]**

Key words: Ambient Networks; Novel Access; Low-Cost Access; Radio Resource Management

1. INTRODUCTION

Cooperation between networks will undoubtedly be important in future wireless networking scenarios in order to offer the user the best possible access according to some criteria. This cooperation will include not only traditional access networks (e.g. GSM, IEEE 802.11, UMTS), but also non-conventional and low cost (NLC) networks. The latter are of particular interest for cost saving and quick deployment; for capacity increase and short payback time; for extending coverage in rural areas, where the investments for deploying a traditional access network are too high; and for new business models, such as privately operated networks. Hence, not only the users, but also the operators will benefit from the cooperation between different parties. However, this cooperation between networks will impose new challenges on Radio Resource Management (RRM).

This paper identifies the most important features of NLC networks, highlighting three different scenarios in which they are likely to be used, each of them mapped onto a specific NLC concept. Using the identified concepts and their characteristics as starting point, the paper analyzes legacy RRM functionalities from a NLC perspective.

2. NLC Concepts

In this chapter we present three NLC concepts studied within the Ambient Network project. Each concept targets one, or a set of, aspects, such as rapid, temporary deployment or affordable infrastructure challenging traditional cellular system deployment concepts. A more detailed description of the concepts is found in [1].

2.1. NLC Concept 1: Low cost and smart coverage extension for rapid and temporary deployment

NLC concept 1 (NLC1) focuses on situations where temporary, low-cost infrastructure has to be deployed rapidly due to increased demand during a constrained time-period (e.g. during the Olympic Games). In this and similar scenarios the new infrastructure serves as a complement to the already existing one (wired or wireless) and it will typically enhance the capacity over an extensive geographical area.

Within this scenario a wired network operator may extend its services to the mobile paradigm, providing service ubiquity. This is depicted in Figure 1, where user B utilizes user A as a forwarding node in order to reach the temporary Local Access Point (LAP) deployed by the legacy wired operator. The LAP might, for example, be placed on a tourism site where third party content providers could adapt services tailored for users present within that particular area, therefore, creating new business opportunities. Furthermore, non-traditional operators, such as railway companies may decide to exploit their existing communication infrastructure to offer wireless access. By doing so, they may increase their revenue substantially with only small up-fronts investments.

The anticipated deployment models for this concept are characterized by operator initiated and supported deployment of temporary networks (including rapid deployment) with access points, fixed & mobile relays and user terminals using multi-hop strategies with single or multi radio access technologies (RAT) to form flexible access networks (including multi-operator case). Furthermore, the "forwarding node" concept introduces a new business dimension, as end users might try to obtain benefits from relaying traffic coming from other users.

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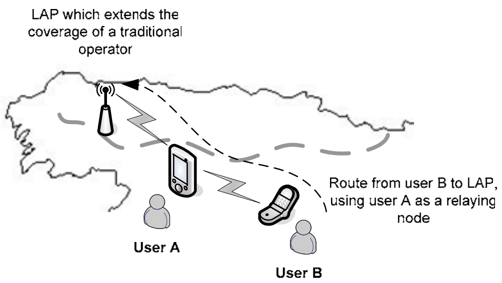

Figure 1. Application Scenario for NLC Concept 1

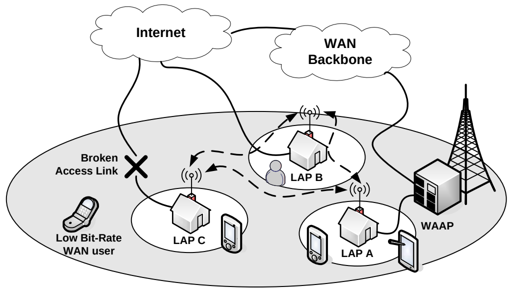

Figure 2. LAP Deployment Example for NLC Concept 2

2.2. NLC Concept 2: Public Access to Privately Operated Local Access Networks

NLC concept 2 (NLC2) is characterized by privately deployed, owned and managed LAPs allowing public access in order to augment capacity and coverage provided by traditional cellular wide-area operators [2]. By "privately" we typically mean private persons and small medium enterprises (SMEs), here denoted as Local Network Operators (LNOs). A similar concept was presented in [3], where it was argued that the there will be a primacy of private, unlicensed systems with full transparency between public and private communication systems in future communication systems.

The major causes for coverage/capacity "gaps" (where traditional wide-area operators are unable or unwilling to satisfy traffic demands) are too high costs and limited deployment flexibility when using conventional technology and business models. NLC2 addresses the problem by utilizing privately operated LAPs for public access and the main application areas are: Deployment adapted to local traffic demand; Low cost, local area coverage for very high bit rates, possibly varying Quality of Service (QoS); and Deployment in homes, offices and public hot zones.

A LAP deployment example is shown in Figure 2 where the large ellipse shows the coverage from the wide-area access point (WAAP) and the smaller ellipses show the coverage zones of the LNOs. The LAPs are typically connected to the Internet through the deployers' private broadband connection (xDSL, cable modem, fixed wireless etc.) but could also be connected directly to a wide-area operator's access network as LAP A in the Figure 2. Since the individual LAPs are unreliable, it is difficult to give strict QoS guarantees. Instead, we assume that a wide-area operator can provide support for real-time services and mobility (e.g. paging) if needed. For increased reliability, several LAPs in an area can form a wireless multi-hop (partial mesh) network in order to mitigate failure or congestion situations in the individual broadband connections. This is shown as the LAP to LAP links in the Figure 2.

2.3. NLC Concept 3: Wide-Area High Bit-Rate Networks with Fixed Relays

Although forthcoming cellular networks will still provide a basic connection to the end user, the bandwidth requirements of new services may easily exceed their capacity, especially in high-dense areas (e.g. cities). To overcome such shortcomings, NLC concept 3 (NLC3) proposes a non-conventional way to increase capacity and coverage at low cost while providing appropriate QoS. The NLC3 architecture consists of a long term (pre-planned) deployment of Fixed Relay Stations (FRSs) within a Mobile Broadband Network (MBN), together with a cellular network overlay called Wide Area-Mobile Network (WA-MN), e.g. UMTS [7], which, also may be improved with relaying strategies. The relay-based operator owned MBN will provide both outdoor and indoor broadband access to terminals with medium velocity of movement and can cooperate with a cellular radio network (WA-MN) to support a high terminal velocity with medium transmission rate. The FRSs should be installed at the edge of the coverage area (as can be seen in Figure 3) of an AP in order to relay the data stream in either layer one, two, or three. By this means the covered area is extended or even "brought around the corner" if the direct line of sight link between the user terminal (UT) and Access Point (AP) is obstructed by buildings.

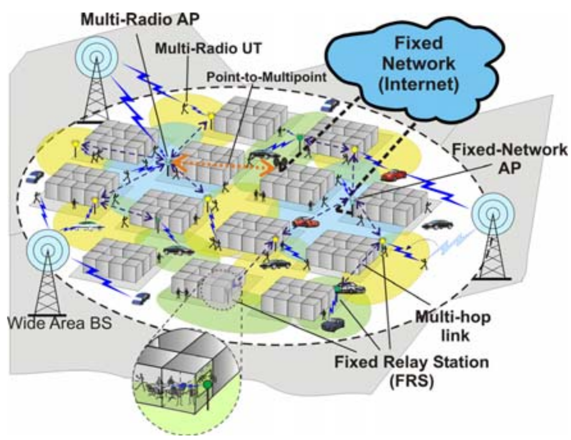

Figure 3. NLC3 Application Scenario

The QoS-support provided in both the MBS and WA-MN will facilitate the seamless continuity of multimedia services during inter-RAT handovers. In short, the main application areas are: Wide area coverage for high bit rates and QoS; Low number of sites with fixed network connection (low cost) by relay techniques; and Long term deployment, but reconfigurable and scalable.

3. RRM FOR NLC

3.1. NLC in Ambient Network Architecture

A main goal for Ambient Networks is to provide functionality for seamless interoperation between heterogeneous networks, in particular in environments with increased competition as well as cooperation [8]. Ambient Networks establishes this interoperation through a common control plane distributed across the individual, heterogeneous networks. The common control plane consists of a collection of control functions and a common control infrastructure. One of the key control functions is Multi-Radio Resource Management (MRRM), which is part of the Ambient Networks Multi-Radio Architecture (MRA) [9].

The NLC concepts described above are an integral part of Ambient Networks. Hence, most of the outlined necessary control functionality should be possible to realize using the common control plane, in particular the MRA architecture and the MRRM functionality.

3.2. Relationship between NLC and MRRM

The NLC RRM issues, which are the focus in this chapter, mostly concern MRRM. On a high-level, the introduced MRRM functionality should enable a cooperative, flexible MRRM between networks belonging to different administrative domains or multiple RATs, and public access to privately operated networks without the need for offline pre-configuration.

Both of these requirements represent cornerstones within the Ambient Networks architecture and they are supported by the capability of the MRRM entities to negotiate their respective roles towards each other using the common control plane of Ambient Networks [4]. Given a more concrete form, this makes issues, such as network advertisements, access discovery, access selection (including evaluation and admission), and overall resource management of utmost importance. In the following, these are discussed, for each of the specific concepts.

3.3. RRM for NLC Concept 1

NLC1 highlights the quick deployment of access alternatives, posing some challenges from the RRM point of view. Two scenarios are used to highlight these challenges. In the first one, a number of accesses are available, so the main issue is to select the most appropriate access, considering various parameters (type of service, user preferences and policies, agreements, etc). The second one, on the other hand, challenges a situation in which the availability of networks is quite low and therefore, the user needs to proactively search for an access.

In the former, a user is using a traditional cellular network (e.g. 3G), but the discovery procedure (either triggered by the terminal or detecting network advertisements) exposes a new potential access, provided by another user that is willing to offer his services as a relaying node towards a non-conventional network. At that moment, network selection procedure is launched, and several parameters are processed in order to select the best alternative. Provided that the service does not have strong QoS requirements, the user would request the relaying node to accept the call, thus using cost as the prominent criteria within the decision process. In this moment, the admission control, distributed among all participating relaying nodes as well as the LAP, is triggered. If the available resources are enough to fulfill the requirements requested by the service, an inter-RAT handover (between the cellular interface and the new one) will occur, and the session will be transferred to the new interface.

In the second application scenario, an infrastructure network is not available. In such circumstances, whenever a user wants to initiate a communication, he must first try to locate a “non-conventional” access element. A practical example of this type of situations is, e.g. a user that is equipped with a cellular phone which has, in addition, another RAT; although he is not able to use the cellular infrastructure (as it is not available), he could try to find a non-conventional access. This potential access element could be another user who is willing to act as a relaying node, or directly a LAP within the user’s coverage area. This scenario poses some clear challenges on the network advertising and discovery procedures. In addition, this application scenario also highlights the necessity of routing procedures for multi-hop topologies, such as route discovery methods, distributed admission control considering multiple hops as well as maintenance procedures, so that the communication link does not break if the relaying node becomes unavailable. This can be done as in legacy multi-hop networks (i.e. looking for another route) or taking advantage of the fact that other access networks are available (overlay structure), so the “traditional” view on Route Maintenance procedure might need to be further developed.

3.4. RRM for NLC Concept 2

To support and exploit NLC2, new RRM functionality has to be developed. Within NLC2, LNOs need to advertise their existence and functional capabilities (RATs) so that roaming users can find, evaluate and possibly utilize the LAP. The presence can either be advertised to the users by the specific network itself or by adjacent networks (proxy advertisements). In the latter case, revenue sharing will probably be necessary.

To enable cooperative resource management between networks belonging to different administrative domains, the LNOs will also advertise their existence and capabilities towards other LNOs in the vicinity. Two or more cooperating networks can share information such as free capacity, used RATs, and backbone transmission resources. Besides enabling common power and spectrum control, which can be used to reduce intercell interference, it will also support more evolved forms of load sharing and admission control. For example, in an area containing several LAPs, the LAPs can form a meshed network in order to share each other's backbone transmission resources as shown in Figure 2.

Within the envisioned scenario there will be a multitude of RATs, provided by several operators. Due to the network heterogeneity, current methods for selecting network that mainly consider signal strength (GSM) or carrier-to-interference ratio (UMTS) are inadequate. Additional parameters that need to be considered are end-user QoS requirements, end-user cost-capacity performance, multi-operator network capacity, revenue of specific operator, fair share of traffic and revenues among operators. Parts of these metrics have previously been reported in [5].

In NLC2 handovers may occur between different RATs (inter-RAT handovers) and different operators (inter-operator handovers). Hard handoffs should always be supported and in certain circumstances fast and smooth handover might be supported. The handoffs can be initiated by either the LAPs (e.g. for load and congestion control) or by the user terminal. In situations where the handoff occurs between loosely integrated networks, we envision that the terminal will have to take a more active part in the handoff procedures. This is in alignment with [6], where it is argued that terminals need to have a more active part in vertical handoffs.

3.5. RRM for NLC Concept 3

NLC 3 challenges RRM in several areas: Relay aware RRM inside of the MBN; Coordinated, cooperative or joint RRM between MBN and WA-MN depending on the level of the established agreements.

There is a strong need for coordination functions which allow at least a coordinated allocation of the available resources inside of the MBN. Therefore the MBN has to be informed about the current capabilities of the system.

When the MBN composes with a WA-MN, both of them can collaborate at several levels. Then the WA-MN can assist the MBN by performing cooperative signaling in the networks even when another operator than the WA-MN owns the MBN. Moreover the level of collaboration may result in a separation of user and control plane traffic.

For a user terminal it should be possible to detect and finally select between the different RATs and it therefore has to be informed about the offered services (e.g. QoS) and costs. A framework must be provided that allows creating, evaluating, and managing network selection policies. As soon as a user changes her QoS demands the network selection algorithm has to verify if the used RAT is still a preferred or possible solution.

When a UT contacts the MBN in order to get access to it, the MBN has to perform the admission control. The MBN therefore needs precise information about the available current state of the system in terms of traffic load, interference conditions and capacity costs. This implies that the needed signaling of RRM information is not negligible. Decentralized admission control schemes could assist the MBN in order to prohibit access as close to the terminal as possible (e.g., FRS, AP).

As soon as the user's QoS requirements change during an ongoing connection this may be a reason for an inter-RAT handover. For this procedure a handover function is needed that coordinates this inter-RAT handover although there is no visible user mobility. This handover may be performed between several operators and therefore special agreements have to be established. In order to perform effective handovers and resource management the joint RRM should gather information about neighboring APs and FRSs in proximity (e.g., current load) and their capabilities as well as alternative RATs.

4. NLC BENEFITS DISCUSSION

This section briefly presents the most relevant benefits that the NLC approach may bring to the end user. The analysis considers the coverage extension the end-user may have due to the NLC approach. In particular, it will study the effect of both the multi-operator and the multi-hop (relaying) concepts that are core ingredients of the three NLC aspects depicted before.

Figure 4 (left) shows the outage probability against the density of nodes, on a square scenario (500 meters side), where AP are deployed uniformly. The coverage area of the single radio access technology is 75 meters; each of the nodes may act as relaying nodes (as brought up in NLC Concept 1), with a probability of 5%. The most interesting result is that there is a large gain when allowing the UT to be two hops away from the AP (compared to the single-hop benchmark) and a relevant one when shifting from two to three hops. However, when further increasing the number of hops, the gain is not relevant. This aspect can be used in order to tackle the complex procedures that have been discussed before (e.g. load balancing, QoS routing) over topologies which are manageable, with the maximum number of hops bounded to a reasonable number.

The right part of Figure 4 highlights the improvement in area outage probability from the multi-operator access selection discussed within the NLC Concept 2. APs are randomly deployed and are assumed to have 100 m coverage radii. Here, operator A and B own 50% of the APs each. As can be seen, there is a significant reduction of outage probability when operators cooperate, allowing operator A's users to connect to B's APs and vice versa. This improvement can be translated to large cost savings since, for a given outage probability, the number of necessary APs that each operator has to deploy is halved compared with the non-cooperative case. In the Figure 4, AP density is varied over a wide range, spanning suburban, urban and hotspot scenarios.

5. CONCLUSIONS

This paper describes RRM challenges and issues for NLC networks, which are expected to play an important role in future wireless networking. Three specific NLC concepts that combine aspects such as rapid, temporary deployment, affordable infrastructure, and public access to privately operated networks, have been described.

The NLC concepts have been used as a framework to analyze legacy RRM functionalities and derive NLC requirements on MRRM. A main requirement is the ability for cooperative, flexible MRRM between networks belonging to different administrative entities through automated mechanisms for negotiation of MRRM roles. Another main requirement is a distributed mode of MRRM operation. The NLC concepts also stress the need for proxy advertisements and an extended set of information to be used for advertisements, access selection, routing, etc. Access selection and load management over multi-radio, multi-hop paths should be possible to realize even for loose collaboration cases. Lightweight mechanisms and lean protocols are necessary to conserve battery power when end user terminals are used as relays.

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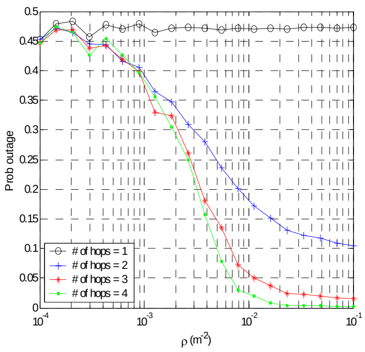

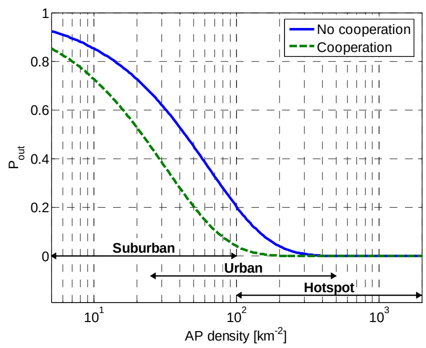

Figure 4. Improvement brought up by the NLC Approach on multi-hop (left) and multi-operator (right)