Application- and Context-Aware Radio Resource Management for Future Wireless Networks

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I. Introduction

The need for a more sophisticated radio resource management (RRM) for future wireless networks arises from the growing importance of wireless technologies in the future Internet. Wireless communication will firstly enable the Internet connection of objects, sensors or actuators and secondly extend the access possibilities to the Internet. The resulting, more seamless integration of the Internet in everyday life will therefore result in a change of the communication paradigm. While communication between people is still predominant in today's Internet, future networks will see a higher share of communication among people and devices. The demand for an ubiquitous Internet access and therewith the importance of wireless access networks will further increase [1].

Hence, future RRM techniques have to account for new application and service requirements, and changing communication patterns. Existing RRM techniques are not suitable for coping with the challenging requirements of the future Internet as they most often aim at optimizing lower layer metrics only and ignore application layer or context information. However, if many different types of applications are jointly to be provided by a wireless network, while at the same time an increased level of user mobility has to be supported, this is not sufficient. In contrast, it is necessary to efficiently adapt the utilization of radio resources to user demands and situations.

In this work, we present two facets of a future, application- and context-aware RRM, which solves these issues. Section II discusses how context information can be exploited for enabling seamless mobility of wireless Internet users. Section III points out the value of application layer information for in-network decisions like traffic shaping or gateway selection. A discussion of the synergies resulting from the combination of the two concepts is presented in Section IV.

II. Context-enhanced Mobility Support

In a heterogeneous wireless network landscape with a growing demand for high data rates, spreading popular user applications, and an increased level of user mobility, higher requirements on user satisfaction arise, therewith putting new challenges on efficient RRM and mobility support. In this section, we present a context-enhanced RRM approach for enabling seamless mobility across different radio access networks (RANs), where characteristics and status of each RAN are accounted for while simultaneously trying to accommodate mobile users, facing different environmental conditions, with the required end-to-end performance.

Context-aware services increasingly rely on data gathered by terminal sensors and (wireless) sensor networks deployed in public places or indoor environments. Sensor data is complemented by information stored in databases. Reasoning mechanisms combine raw data to infer higher level context information e.g. required for service adaptation. User and network context, in particular location information and movement prediction, can be used for optimizing mobility support. Furthermore, adapting the system behavior according to current context of the network, the user, and the terminal can yield significant improvements in end-to-end performance and resource utilization. Radio resource allocation and utilization decisions may be influenced by network operator policies, service level agreements, user preferences [2] and location information, or as a result of sophisticated resource utilization analysis [3]. Inherently related to RRM is the issue of when to change the user's point of attachment (PoA) to a specific network to another network due to user movement or limited resources in the former one, also referred to as "handover". Besides features such as "always on" and "always best connected" an efficient use of the heterogeneous landscape of RANs shall be achieved. Therefore, a context-enhanced RRM will be able to exploit not only radio network parameters but any available context information of the users. However, since each wireless access network provides a different level of Quality of Service (QoS), capacity, and coverage, various parameters have to be accounted for to ensure satisfying end-to-end performance. For evaluating possible connections between terminal and PoA, relevant context parameters are normalized and added up, where each context parameter is weighted with a certain confidence level, relevance, and costs for information retrieval [4]. A handover of the currently active connection of a terminal to a specific PoA is only performed if the maximum of a weighted sum for a specific PoA exceeds the current connection quality plus a pre-defined margin. This margin, besides ensuring a better connection quality in absolute terms, allows for trading off handover costs

This work was funded by the Federal Ministry of Education and Research of the Federal Republic of Germany (Förderkennzeichen 01 BK 0800, GLab). The authors alone are responsible for the content of the paper.

against enhanced connection quality, where handover costs are not limited to signaling costs but also comprise costs for acquiring, processing, and evaluating context information.

III. Application-Aware Resource Management

Clearly, the fragmented heterogeneous wireless Internet access landscape necessitates an advanced mobility support for guaranteeing a seamless wireless Internet experience. The degree of heterogeneity of the predominant Internet applications P2P or client-server file sharing, web browsing, gaming, or video streaming is however similarly large [5]. Since different applications have different quality requirements, it is vital to enable application specific service guarantees in order to ensure a high Quality of Experience (QoE) after a successful handover and for stationary clients.

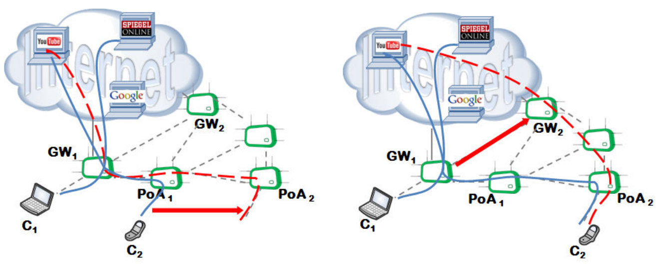
Future networks must therefore put an end to today's concept of using access networks as bit pipes where the network does normally neither know which data traffic it is carrying nor which service guarantees and quality requirements apply. Consequently, we propose to exchange information between the network and the client. This overcomes the information asymmetry in application-network communication and thereby enables an intelligent application-aware cross-layer RRM. Additionally, a QoE-based RRM that continuously adapts the network resources to quality feedback from the application becomes possible. QoE-based RRM is advantageous if the application requirements in terms of static QoS parameters can not be specified in advance, which is the case for the majority of the applications. We therefore propose to trigger network management decisions by a tool running at the client that monitors the application comfort (AC) which quantifies how well an application is running and in particular, enables a prediction of the user experience. This firstly, overcomes the issue of complex flow classification and secondly, allows to react before the QoE is degraded.

We realize our concept of an AC-based resource management architecture in a wireless mesh network (WMN) environment for YouTube video streaming. This is on the one hand motivated by the increasing number of users accessing the Internet over a WMN. On the other hand, this is a challenging type of networks as the decentralized structure of WMNs makes it difficult to achieve service guarantees. We choose YouTube, as YouTube and flash video streaming portals in general, make up for roughly 10% of the traffic volume of private households which use a WMN as Internet access network [5]. The key component of our architecture is YoMo [6], a lightweight Java tool running at the client which detects the presence of a YouTube flow and signals this to resource management tools which may either restrain the bandwidth of concurring best effort flows or change the Internet gateway over which the YouTube flow is routed. Additionally, YoMo continuously monitors the YouTube AC which is defined as the amount of playtime β, the player can continue playing if the connection to the server is interrupted. YoMo sends an alarm message to the RRM tools as soon as β falls below a threshold and thereby avoids a stalling of a YouTube video which would negatively affect the user experience.

Experiments in a congested WMN testbed demonstrate the attractiveness of AC monitoring for both customers and network providers, as using YoMo for RRM decisions is able to guarantee the successful YouTube video playback. If, in general, users run YoMo or a similar tool and the network uses this information for resource management, both parties may greatly benefit as the provider gets valuable information for improving the user QoE for specific applications.

IV. Synergy of Both Approaches

In Fig. 1, a simplified example where context-enhanced mobility support and application aware RRM are necessary to enhance the experience of mobile users accessing different Internet services is depicted. In this case, the use of context information, in particular location and movement prediction, allows for providing the mobile user C_2 with suitable wireless access possibilities and, thus, significantly enhances the mobility support across different RANs (cf. Fig. 1(a)). Additionally, information on the application running on C_2, YouTube in this case, and on the load of the Internet gateways allows to apply RRM actions, in this case to reroute the YouTube flow to another gateway, in order to avoid a QoE degradation (cf. Fig. 1(b)). This example hence demonstrates that an application- and context-aware RRM, that takes user, network, and application context into account, is an enabler for enhanced mobility support and a guarantee for superior users satisfaction in future wireless networks.



(a) Mobility support (b) Gateway selection

Fig. 1. Mobility support and resource management in wireless mesh networks

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