Access Schemes for Mobile Cloud Computing

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***Abstract*—Mobile Cloud Computing is widely accepted as a concept that can significantly improve the user experience when accessing mobile services. By removing the limitations of mobile devices with respect to storage and computing capabilities and providing a new level of security by a centralized maintenance of security-critical software for e.g. mobile payment applications, it is expected that it will find broad acceptance on the business as well as consumer side. Research indicates [1] that Mobile Cloud Computing will additionally help to make visions of context-aware services become reality. However, Mobile Cloud Computing concepts rely on an always-on connectivity and will need to provide a scalable and - when requested - high-quality mobile access. "Intelligent access" schemes meeting these requirements will be discussed in this paper. They exploit the specific information available by the "Mobile Cloud Controller", i.e., the users' location, context, and requested services, and significantly evolve the Heterogeneous Access Management schemes developed for the traditional heterogeneous access scenarios. In order to evaluate the performance of these intelligent radio access management concepts in the framework of mobile cloud computing, a specialized radio network simulator will be introduced. It will be shown that a Mobile Cloud Controller establishing a Context Management Architecture can provide the requested availability and quality of mobile connectivity.**

I. Introduction

The concept of Mobile Cloud Computing (MCC) intends to make the advantages of Cloud Computing available for mobile users but will provide additional functionality to the "cloud" as well. Mobile Cloud Computing (MCC) will help to overcome limitations of mobile devices in particular of the processing power and data storage. It might also help to extend the battery life by moving the execution of commutation-intensive application "to the cloud". However, a significant gain in battery stand-by time will require that the wireless connectivity for the MCC operation is at least as energy-efficient as the state of the art. MCC is also seen as a potential solution for the fragmented market of mobile operating systems with currently eight major operating systems.

Other benefits that might be realized by the introduction of MCC are

- an increased security level for mobile devices achieved by a centralized monitoring and maintenance of software, and
- a one-stop shopping option for users of mobile devices since Mobile Cloud Operators (MCOs) can simultaneously act as virtual network operators, provide e-payment services, and provide software, data storage, etc. as a service.

In addition to these well understood advantages, a number of new business roles and technical functionalities might be provided by mobile clouds. Here, in particular the introduction of mobile clouds as platform for the provisioning of context- and location-awareness enabling personalization is seen as attractive business case. On a strategic level, mobile cloud computing might open the cloud computing business that is currently almost exclusively addressing businesses to consumers since they will significantly benefit from the above described options. In order to introduce mobile cloud computing and to realize the mentioned visions, there are however a number of challenges to address. The most critical is probably to guarantee a wireless connectivity that meets the requirements of mobile cloud computing with respect to scalability, availability, energy- and cost-efficiency. This paper focuses on this topic and will describe concepts, evaluation methodologies and performance results for intelligent mobile access schemes that exploit context information provided by the Mobile Cloud. Today, context and location information is already used by a broad variety of applications, in particular context-aware services for mobile terminals. These services exploit data collected from terminal sensors (e.g., GPS, gyro, proximity detectors), sensor networks [2], or network sensors measuring network status and load. Not only consumer applications but also network services exploit this information. Classical so-called "intelligent access" concepts are assuming that all categories of dynamic context information (user profiles, terminal status and sensor information, external sensor networks, and network status) can be used to optimize the mobile access. The requirements on the wireless connectivity for Mobile Cloud Computing differ in a number of important details from these classical heterogeneous access scenarios:

- MCC requires an "always-on" connectivity for a low data rate cloud control signaling channel.
- MCC requires an "on-demand" available wireless connectivity with a scalable link bandwidth.
- MCC requires a network selection and use that takes energy-efficiency and costs into account.

The solution presented here assumes that we deploy MCC in a heterogeneous access scenario with a wide range of different radio access technologies available, e.g., GPRS, WCDMA/HSPA, LTE, WiMAX, cdma2000, WLAN, and that context information, such as terminal locations and capabilities and user profiles, can be used by the mobile cloud controller to locally optimize the access management (cf. Fig. 1).

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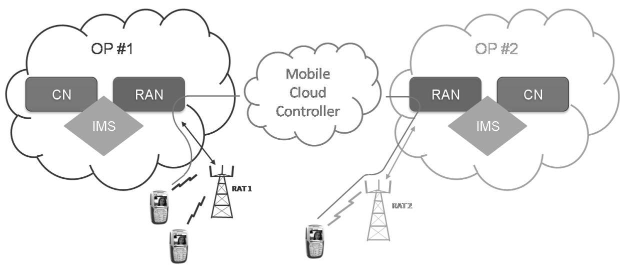

Fig. 1. Mobile Cloud Controller in a heterogeneous access scenario

Moreover, add-on functionalities, such as AAA or charging, can be integrated using IMS. We also assume that the low data rate signaling cloud control channel is available. It might for example be provided by GPRS that is deployed in many countries with a very high coverage and already used for background low data rate machine-to-machine communication. Energy- and cost-efficiency can well be described in terms of the required radio resources. The "on-demand" request for scalable wireless connectivity is described by a statistical model derived from classical TCP/IP models for mobile users where the parameters were modified in order to model expected mobile cloud traffic. This model is intended to describe consumer and not business use of MCCs since research, e.g., ABIResearch [1], expects that the majority of the mobile cloud users will belong to this group.

II. Network Selection and Heterogeneous Access Management

In a more and more fragmented and heterogeneous wireless network landscape and with an increasing demand for high data rates or even on-demand scalable transmission bandwidth as for MCC scenarios, the need for efficient network access management across different radio access technologies (RATs), referred to as "heterogeneous access management" (HAM), becomes eminent. Radio resources are of course limited due to physical, technology-specific and regulatory constraints. Context, either provided by terminals, network nodes or from sensors deployed in the user's environment, will be utilized to significantly reduce the waste of scarce radio resources and efficiently manage wireless access across heterogeneous RATs.

The issue of network selection in an environment of diverse wireless access possibilities is widely addressed in today's research. HAM describes a concept for controlling radio resource allocation and utilization, as e.g. bandwidth, power, etc., across various RATs, where the main goals are to optimize overall system performance and to enable seamless mobility. HAM decisions and actions may be influenced by network operator policies [4], service level agreements [5], user preferences [6], user location information [7] or as a result of sophisticated resource utilization analysis [8]. Further, the integration of a multitude of wireless access networks under a cross-layer context-aware architecture [9] has shown to increase user satisfaction and network throughput.

Inherently related to HAM is the issue of when to change the user's point of attachment to a specific network to another network due to limited resources in the former one, also referred to as "handover". Hence, the availability of network context is a prerequisite for efficient handover decisions.

However, the afore mentioned approaches exhibit no feature for controlling the quality of context used for network adaptation and HAM decisions, thus, not preventing that adaptations may lead to performance degradations due to inadequate context quality. The above described specific requirements for MCC were not yet addressed in this combination.

A. *Context Awareness*

The notion of context awareness can be found in manifold variations in different research areas of computer science. On the one hand, context consumers, such as context-aware applications and services, require context information in order to adapt to changes in their environment. On the other hand, context providers, e.g. sensors and (wireless) sensor networks, are key components for detecting the requested context. Moreover, GPS modules, temperature, ambient light, and acceleration sensors are becoming widespread with the recent success of smart phones and other mobile devices. For categorization of context sources, Chen [10] proposes the following classes:

1) *Direct access to sensors* - Sensors deployed on network terminals can collect environmental context such as location or temperature as well as network context information.
2) *Middleware infrastructure* - The introduction of middleware infrastructure aims at strictly separating the processes of context acquisition and context management. The separation improves system extensibility and reusability.
3) *Context server* - In this approach, a resource-rich context server takes over the task of administering context data that it receives from various context sources. It relieves sensors and terminals from managing context requests from other entities.

Context management systems acquire, process, manage, and distribute context information according to the specific needs of applications and services. Exploiting the available context information for improving network performance is a meaningful application beyond conventional end consumer services such as location-based services. However, in both cases, a context management system is required in order to properly supply the application with context, thus making it "context-aware". Many of the early context-aware systems in science have just been location-aware. The Active Badge Location System by Want et al. [11] was one of the first context-aware applications. The current location of a user was determined using infrared-based techniques. In the 1990s, location-aware tourist guide systems were developed that replaced or complemented traditional tourist guides [12], [13], [14]. Meanwhile, there have been improvements with regard to both architectural frameworks for context-aware systems and the diversity and quality of available context information (e.g. advanced positioning technology [15]). European projects such as SPICE [16] and MobiLife [17] have set milestones in integrating

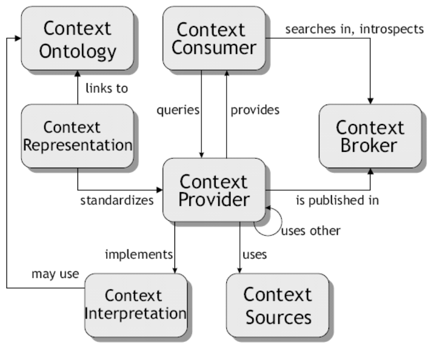

Fig. 2. MobiLife Context Management Framework

context awareness functions into their respective architectures. Figure 2 depicts the MobiLife context management framework with its split into relevant functions. Other authors, such as Chen [10], have proposed agent-based approaches. However, all of these frameworks miss a comprehensive concept for the consideration of context quality. Furthermore, they have often been designed according to requirements of end-consumer services, e.g. location-based services, whereas the proposed context management system can also supply context information with regard to requirements of IRNA.

III. A Concept for Intelligent Radio Network Access for MCC

The heterogeneity of today's wireless access possibilities imposes challenges for efficient access and resource management across different RATs. The proposed IRNA concept, as shown in Fig. 3, accounts for the characteristics and status of each RAT while simultaneously trying to accommodate users, who face different environmental conditions, with the best possible end-to-end performance.

Since the use of context information available to the MCO enriches the information basis on which HAM decisions are taken, network selection and handover decisions will be significantly improved, given context such as network load and user movement predictions is available. However, the MCO will not necessarily have access to the intra-RAT resource information. Here, we assume that context information about the network status is only available by reports of the terminals measuring network parameters. This information will of course be subject to estimation errors and signaling delays. Therefore, modeling of the quality of context is relevant.

The *a-priori* knowledge of available access networks within reach will significantly reduce terminal scan times for access networks, yielding decreased terminal power consumption. Multicasting streams will be efficiently rerouted and transmitted knowing terminal capabilities and points of attachment [18]. Mechanisms of modern wireless RATs as e.g. link adaptation will also benefit from detailed context information such as user environment and history information of certain hotspots.

A suitable framework for network context exchange is IEEE's 802.21 working group proposal [19], which aims at

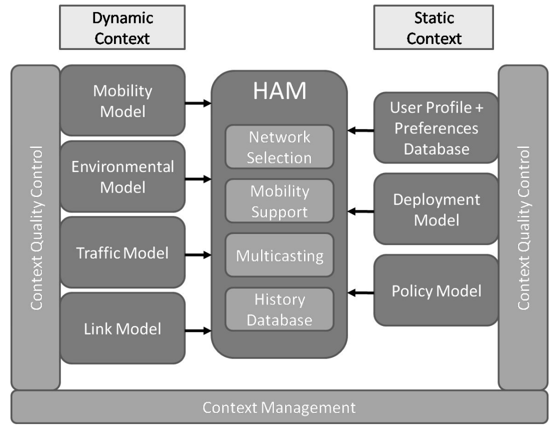

Fig. 3. Concept for Intelligent Radio Network Access [3]

providing support for inter-system handover and seamless mobility. Network context, either retrieved from network nodes (e.g. access points) or from terminals, is exchanged using 802.21's "media independent handover function", so that relevant parameters such as load and traffic statistics can be generated by HAM. However, for MCC an over-the-top implementation of this protocol might be required.

Since each wireless access network provides a different level of Quality of Service (QoS), capacity and coverage, various parameters are accounted for to ensure satisfying end-to-end performance. Relevant parameters are either static (e.g. system bandwidth) or dynamically changing due to users' movements and environmental conditions (e.g. received signal strength). While static parameters will be retrieved from databases, dynamic parameters need to be measured, monitored and assessed.

In case that n real-valued, non-negative context scopes are available for HAM, we can denote their values at time t as $x_{1,t}, x_{2,t}, ..., x_{n,t}$ where each of the scopes can lie within an interval $[l_k, u_k]$, $k = 1, 2, ..., n$ that is relevant for IRNA decisions. Values lying outside their respective interval have to be considered separately. In order to normalize different context scopes to the interval $[0, 1]$, each $x_{k,t}$ is divided by the respective interval width $u_k - l_k$:

$$x'_{k,t} = \frac{x_{k,t} - l_k}{u_k - l_k} \tag{1}$$

In the domain of heterogeneous access management, the majority of context scopes have to be considered per user (or terminal) and base station since they describe a characteristic of the connection between the terminal and the base station. An example would be the signal strength of different WLAN access points detected by different user terminals. Hence, it is necessary to more specifically denote context values with two additional indexes i and j, where i represents the terminal and j the base station. However, scopes exist that fulfill $x_{i,j,k,t} = x_{j,k,t}$, i.e. context scopes being equal for all i, e.g. the current number of users attached to an access point. Moreover, we can weigh the normalized context values according to their relevance ($r_{i,j,k} \in [0,1]$) for the evaluation of the (possible) connection and their confidence level ($c_{i,j,k} \in [0,1]$). In conjunction with (1), this yields

$$x''_{i,j,k,t} = c_{i,j,k} \cdot r_{i,j,k} \cdot \frac{x_{i,j,k,t} - l_{i,j,k}}{u_{i,j,k} - l_{i,j,k}} \tag{2}$$

For decisions related to HAM, it is crucial to find (based on available context information) the best radio connection for a single terminal, taking into account overall system performance. Hence, for every point in time t, the quality of each (possible) connection to the available point of attachments j (base station, access point, etc.) is evaluated by calculating

$$q_{i,t}(j) = \sum_{k=1}^{n} x'''_{i,j,k,t}, \tag{3}$$

where $x'''_{i,j,k,t} = x''_{i,j,k,t}$ if $x'_{k,t}$ is positively correlated to the evaluation of the possible connection, i.e. an increasing value of $x'_{k,t}$ yields a high-rated connection (e.g. received signal strength), and $x'''_{i,j,k,t} = 1 - x''_{i,j,k,t}$ if $x'_{k,t}$ is negatively correlated to the evaluation of the possible connection, i.e. a decreasing value of $x'_{k,t}$ yields a higher rating (e.g. distance to point of attachment). For every terminal i, the maximum $q_{i,t,\max}$ of all $q_{i,t}(j)$ identifies the (theoretically) best point of attachment to be connected to. However, this does not take into account cost associated to an executed handover (such as terminal battery power, use of network resources, etc.). If $j = j_0$ denotes the point of attachment for the currently active connection of the terminal, we define a margin $y_{i,j}$ by which $q_{i,t,\max}$ has to exceed $q_{i,t}(j_0)$. Thus, the handover is only performed if

$$q_{i,t,\max} > q_{i,t}(j_0) + y_{i,j}. \tag{4}$$

The margin $y_{i,j}$, besides ensuring a better connection quality in absolute terms, allows for trading off handover costs against enhanced connection quality, where handover costs are not limited to signaling costs but also comprise costs spent for acquiring, processing, and evaluating context information.

Further, in order to beneficially adapt to the dynamics described by this linear, terminal-centric MCC model, gathered context information must fulfill certain requirements in terms of context quality, where relevant quality criteria are availability, accuracy, topicality, delay, relevance and confidence. Thus, the use of context information for optimizing HAM and system performance requires quality control and management of the acquired context information. The aim of our proposed context management architecture is to adaptively control and manage context information according to the requirements of the Context Consumer, e.g. HAM module.

IV. A Context Management Architecture for IRNA-MCC Purposes

Ideally, context management systems should be agnostic with respect to their application. However, depending on the intended utilization of context information, context management concepts have to comply with different requirements. In this section, we propose a context management architecture (CMA) that is based on the producer-consumer role model that can frequently be found in the area of context management, e.g. [20]. The CMA is designed to acquire, manage, and distribute context information and to control the context quality required for IRNA purposes. This functionality requires the following core architectural components:

- Context Provider
- Context Broker
- Context Consumer.

Moreover, a context quality enabler (CQE) is responsible for controlling quality of context. The Mobile Cloud Controller can but does not need to operate the Context Broker (platform). We assume that the Mobile Cloud, on the one hand, provides context-aware services and, on the other hand, uses context information for the intelligent radio access management.

A. Context Provider

The Context Provider (CP) is the logical point in the CMA where context information originates from and is provided to other entities of the architecture. The types of context data a CP provides can be classified in (relatively) static data on the one hand and dynamic data on the other. Static data for instance includes terminal capabilities, user preferences or user information retrieved from social communities on the web. However, for the purpose of managing IRNA, dynamic context information, such as user location and movement (i.e. speed and direction) and network conditions have a higher relevance. Additionally, CPs that apply reasoning algorithms on low-level context data are able to abstract and predict user behavior, e.g. user movement. The communication between CPs and other CMA entities occurs in a synchronous mode, i.e. CPs directly reply upon context requests. For initial advertising of its capabilities and availability to the architecture, the CP sends an announcement containing the respective information to the Context Broker.

B. Context Broker

The Context Broker (CB) takes on the role of a middleman. Its main functionality is to maintain a registry of available CPs and their capabilities based on the announcement sent by CPs. Based on that registry, it can provide a CP look-up service to entities searching for certain context data. In addition, the CB can provide context data itself by forwarding the data it has received from CPs. Two different communication modes are available for requesting entities. In the asynchronous mode, context is forwarded if a specified condition or event comes true (”publish/subscribe mode”). In the synchronous mode, a request for context information is instantly answered by the CB (”request/provide mode”). In order to allow for forwarding of context, the CB itself maintains a context cache where it stores context that has not expired yet. Expired context is moved to the context history database where it can be accessed by the CB if necessary.

C. Context Consumer

Context Consumers (CC) are entities that use context data as an input for their actual functionality. Network services, applications for end users, service enablers or actuators in wireless sensor and actuator networks are exemplary consumers of context information. The CCs we focus on here consist of different components of the IRNA framework as shown in Fig. 2. CCs can request context from the CB or they can invoke an URI of a CP at the broker. Consequently, CCs can establish a direct communication with the according CP.

D. Context Quality Enabler

Context-aware systems managing IRNA in a dynamic, multi-technology, multi-vendor environment have to perform a multitude of tasks to optimize network utilization. In order to make the right decisions in terms of network selection, link adaptation, prediction of user behavior, and multicasting, IRNA modules require context data of high quality. The integration of a Context Quality Enabler (CQE) into the CMA assures that only context information that adheres to the stated quality criteria will be used for IRNA management. Accordingly, only CPs with the corresponding characteristics are able to deliver the appropriate context data. Consequently, the CQE is attached to the CB since it is the broker that disposes of information on CP capabilities and availability. Thus, when requesting context information, HAM also sends minimum requirements with regards to context quality. The CQE uses this information for filtering context information accordingly. Moreover, the CQE might identify malicious context providers or terminals that intentionally try to impair system performance by using either context information of other terminals as reference value or implementing fairnes and penalty policies, respectively. The reference values can bes determined using either latest context information of available CPs or terminals or accessing the history database. Further in case no available CP that matches HAM's context require-, ments can be found, the most appropriate CP will be selected, where its context will be tagged with reliability information.

E. Overall Architecture

Figure 4 shows how the entities presented in the previous sections are integrated into the CMA. The main part of communication between a CC and a CP takes part via the CB. However, CCs have the possibility to request the URI of CPs at the broker (CP look-up service). Using this URI, they can communicate directly to a CP and request context data, thus speeding up context data delivery. As described above, the CQE receives information about the context quality that is required by the requesting CC. If the CC invokes the look-up service at the CB, the CQE filters out URIs of CPs whose data do not match the required quality level. Similarly, data is filtered if a CC requests context information from the CB.

The conceptual outline of the architecture allows for controlling context quality according to the needs of the CCs. Depending on the actual implementation of the CQE, context quality can be controlled with respect to different criteria.

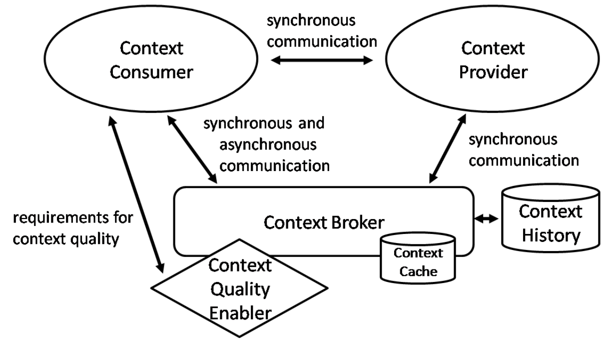

Fig. 4. Context Management Architecture

These criteria in turn should reflect the requirements of the application using the context data.

V. A Context-Aware Radio Network Simulator (CORAS)

In order to evaluate the performance of radio access schemes for Mobile Cloud Computing, a radio network simulator taking context information into account is required. The proposed Context-Aware Radio Network Simulator (CORAS) incorporates static as well as dynamic context models to simulate the influence of context quality on HAM and users' end-to-end performance. For the assessment of HAM network selection decisions and resource utilization, RAT deployment and policy models as well as terminals performing random walks are simulated taking signaling costs and occurring handover delays into account. Network selection decisions, based on signal strength indications and user movement predictions, and resource utilization are monitored and evaluated. Throughput and network load analysis is performed reflecting the influence of context quality.

Context quality is controlled with respect to the criteria availability, accuracy, delay, confidence, and relevance for assessing link quality. For instance, current network capacity is modeled based on past capacity and instantaneous capacity estimation. However, data on instantaneous capacity is only available with a certain delay. The smaller this delay, the better the quality of context information (in this case capacity) and, hence, the better the instantaneous resource utilization. Further, preliminary simulation results have shown that a delayed user movement prediction with respect to speed and direction increases the number of handovers. Thus, worse context quality (in this case a less accurate and delayed movement prediction) results in less effective resource utilization. Moreover, the environmental model (cf. Fig. 3) takes fading effects, i.e. degradation of signal strength, into account. The timely availability of this context information improves measures for link adaptation. Finally, currently detected signal strength, which is measured and reported by each terminal, is an important trigger for handover decisions. Varying context quality, in this case changing accuracy and delay of signal strength measurements, heavily influences the number of unnecessary handovers.

Similarly, the quality of additional context parameters can be manipulated, yielding an approach that allows to demonstrate the impact of different levels of context relevance, confidence, and quality on IRNA performance.

The traffic model is defined according to the above mentioned mobile TCP-IP model that was adapted to reflect mobile cloud traffic.

VI. Conclusion and Next Steps

Intelligent Radio Network Access (IRNA) provides a solution for one of the most critical challenges of Mobile Cloud Computing (MCC). This paper presents a framework for the use of context information for the Heterogeneous Access Management (HAM) provided by the Mobile Cloud as a service for the mobile terminals. A formal method assessing link quality based on available context information has been developed for triggering handover mechanisms. The proposed Context Management Architecture (CMA) is responsible for acquiring, processing, managing, and delivering context information. Since the always-on availability and on-demand scalability of the wireless connectivity is a key requirement for MCC concepts, the "quality" of context information is crucial for the purpose of IRNA, especially with regard to delay, accuracy, relevance, and confidence. A Context Quality Enabler (CQE) is therefore incorporated into the architecture. The CQE controls the provision of context information according to the requirements of the Mobile Cloud Controller. Finally, based on the outlined HAM concept, we presented a context-aware radio network simulator (CORAS) that is able to model context availability, accuracy, and delay, thus enabling an evaluation of the impact of different levels of context relevance, confidence, and quality on simulation results.

An extensive simulation campaign will be carried out in the near future to evaluate the potential benefits of incorporating context information for MCC that are expected to vindicate the induced context processing overhead.

VII. Acknowledgments

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