A UCWW CLOUD-BASED SYSTEM FOR INCREASED SERVICE CONTEXTUALIZATION IN FUTURE WIRELESS NETWORKS

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Abstract: This paper describes the design and development of a novel cloud-based system for increased service contextualization in future wireless networks. The principal objective is the support of mobile users (consumers) in a Ubiquitous Consumer Wireless World (UCWW) seeking to choose and select the 'best' service instance in a UCWW environment matched to their dynamic contextualized and personalized service delivery requirements and expectations, thereby increasing user freedom in where, when and how they access desired services, and increasing user-driven networking. The design challenges to create such a cloud-based system with an ever-enhanced capacity to be attuned to a user-client's dynamic contexts, and do this for all its users, are addressed, and software infrastructural design solutions suggested. The cloud idea proposed here is one which should yield efficiencies and saving for consumers, operate as an additional 'behind-the-scenes' decision support subsystem to make smart decisions based on mining of the most up-to-date data stored in the cloud repositories related to service contexts and personalized profiles. Rather than the use of known efficient heuristic methods employed with large and complex data structures, together with associated algorithms solving the combinatorial optimization problems, an alternative method, proposed here for making predictions, is to discover patterns in the behaviour of the individual client-consumer, to bring into play, in the decision process, patterns and trends of other client-consumers seeking the same or similar services, and also the constant update of the user's wireless environment context through information garnered from other sources, such as wireless access service provider updates, teleservice provider updates, and data sensed by the sensors in the environment. Indentifying and addressing the need as directly as this is a novel approach towards providing context-aware personalized services. It is particularly novel, and desirable, in the UCWW context. Hence, this consumer supportive smart repository solution may appropriately be called a UCWW cloud. The paper sets out an infrastructural design of this cloud, ordered within a conceptual UCWW software architecture, together with its various elements, e.g., decision support subsystem and mobile network environment elements of personalized information retrieval (PIR).

1 INTRODUCTION

The research described in this paper is motivated by the context-awareness and service contextualization problems within the Ubiquitous Consumer Wireless World (UCWW) environment. The UCWW, proposed in (O'Droma, 2007) & (O'Droma, 2010), sets out a generic consumer-centric techno-business model foundation for future generations of wireless communications. The evolution of the UCWW environment represents a shift from the currently dominating subscriber-based access to wireless communication services, towards more consumer-centric one. By utilizing a person-centric IPv6 address scheme, enabling full number portability as well as an access-network-independent third-party

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authentication, authorization, and accounting (3P-AAA) service provision, consumers can dynamically select a provider for a service from a list of alternatives. This in turn opens up the opportunity for stronger competition between providers and as such, to an improved level of service for the consumer. Effective exploitation of the attractive benefits of this freedom will need the support of ‘smart’ software tools. These will dynamically collect and sort through the vast numbers of service options on offer to a consumer at any time and place, which might otherwise be overwhelming, and extract service-type-dependent ranked choice suggestions matched to the consumer’s relevant profile.

In support of these tools and of the whole consumer-choice optimization process, we propose here the development of a UCWW cloud-based system to facilitate the delivery of increasingly contextualized services in future wireless networks. Through this user-centric UCWW cloud, mobile users can have access to a more contextualized level of service provision, with a much greater level of choice in terms of service delivery. Moreover, service providers can deliver a much more specialized level of service, to a much larger set of mobile users.

The main goal in our work is to provide the user with a context-aware software tool that can assist the user to choose and select the ‘best’ service instance in a UCWW environment. Through an appropriate graphical user interface (GUI) the tool may make the service choice easier or may make the choice on behalf of the user when authorized to do so. In both cases, the software tool would benefit greatly from the ability to make accurate predictions of user preferences in particular situations, i.e., making the choice of one particular mobile service instance (provider) when the user desires to use a specific service. This prediction may be the result of solving a combinatorial optimization problem, where the user has specified criteria for making a particular choice. For example, the GUI may allow the user to specify a few parameters such as an upper bound on the price, lower bound on the quality of service (QoS), etc. The difficulty is both computational – often such problems are NP-complete (Garey, 1979) – and related to the limited hardware resources on mobile devices, which may not allow the use of large and complex data structures and algorithms. Therefore, efficient heuristic methods must be used, particularly for the context of solving the combinatorial optimization problems (Wolsey, 1999) & (Cook, 1997) on mobile devices. An alternative method for making predictions is to allow the software to discover patterns in the behaviour of the consumer. In order to achieve this, the user behaviour should be recorded, stored and uploaded as appropriate to a distributed repository. On behalf of individual users, but for many users, this will allow always best connected and best served (ABC&S) applications, within the distributed repository, to carry out effective mining of data (Usama, 1996) & (Mikut, 2011) that may result in more accurate and more beneficial user behaviour predictions (Witten, 2011). Such a repository can be viewed as a *UCWW cloud* that facilitates data storage and offers service predictions based on the patterns discovered within the user data.

For this, foremost cloud computing principles and techniques need to be employed along with effective data collection and data mining techniques to facilitate predictions as to the applicability of services to particular users. The impact of this work will be to provide a more consumer-centric wireless services environment, which can also be commercially attractive to service providers.

The rest of the paper is organized as follows. Section 2 provides an overview of the UCWW. Section 3 presents the UCWW cloud as a context-aware middleware. Section 4 describes the decision support subsystem of the UCWW cloud. Section 5 considers the implementation issues. Finally, section 6 concludes the paper and suggests future research directions.

2 UBIQUITOUS CONSUMER WIRELESS WORLD (UCWW)

Being a wireless communication environment rather than a wireless technology, and while requiring some distinct technological infrastructural modifications and innovations (O’Droma, 2007) & (O’Droma, 2010), UCWW is completely in harmony with, and will benefit fully from, almost all the existing global technological developments and ongoing standardization efforts in wireless communications, e.g., Next Generation Mobile Networks (NGMN) Alliance proposals (Kibria, 2007), 3rd Generation Partnership Project's (3GPP) Long-Term Evolution and System Architecture Evolution (LTESAE) (Ekstrom, 2006), and ITU-T's ongoing work on Next Generation Networks (NGN) (Carugi, 2005). The primary change UCWW brings is that, through it, users become consumers instead of subscribers. The ‘in harmony’ element of this evolution is emphasized by the fact that UCWW consumers may opt out (or in) of having such subscriber-like contracts, or may have several simultaneously through a single Consumer Identity Module (CIM) card and without conflict with different access network providers (ANPs). While it is evolutionary, it enables significant and new user-driven wireless communication capabilities and benefits, and converting the wireless environment into a consumer-centric one. True user-driven ABC&S paradigm (Passas, 2004) may be considered to encompass many of these benefits, and more. Most are obviously inherent and distinctively characteristic of UCWW; others are not, e.g., the user-driven integrated heterogeneous networking (IHN) and interworking – a published amendment to an existing ITU-T recommendation standard for the latter is shown in (O'Droma, 2010). In this, UCWW marks a seismic shift from the network-centric, subscriber-based techno-business model (SBM) of today, with its long-term lock-in type contract between the subscriber and the ANP, with all its constraints, to a new consumer-centric techno-business model (CBM).

Figure 1 portrays schematic representations of both techno-business models (SBM & CBM), illustrating the main mobile service paths and business agreement relationships. Transition to the UCWW, where the new CBM environment may co-exist side-by-side with the SBM environment, is shown as a passage through a global standardization frontier.

In SBM, the subscriber primarily gets wireless services through his/her 'home' (cellular) ANP or from visited-ANPs, if roaming agreements are in place. WiFi hotspots, Femto-cells and the like, when they offer services using the AAA infrastructure of a user's home-ANP, come under the visited-ANP umbrella. Teleservice providers (TSPs) and value-added service providers (VASPs) can also offer their own services through access networks under respective bilateral business agreements.

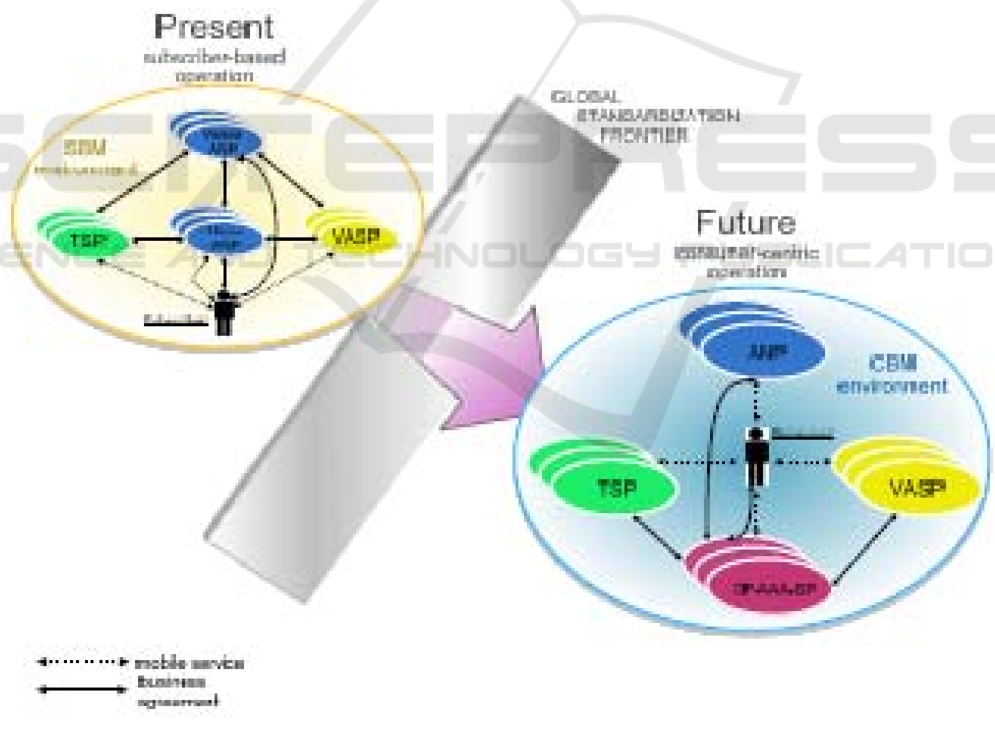

Figure 1: Subscriber-based (SBM) and consumer-centric (CBM) techno-business models.

The main downsides of SBM, mainly linked to the 'lock-in' constraint of the (long-term) subscriber contract with a home-ANP, include: roaming charges which are often perceived as non-cost based, domination of ANP marketplace by a few large operators, poor market openness for new or niche ANPs due to prohibitive start-up costs, limited 'number portability & mobility' among ANPs. In regard to the latter, subscribers who desire to move ANP, rather than porting their number, tend to the easier solution of buying a new (U)SIM card with another phone number in the other network. *Spinning* is another popular approach whereby subscribers, using multiple-(U)SIM-card phones, can choose to operate on any one of ANPs at any time. However, this is still quite far removed from the full ‘number portability & mobility’ within the CBM, where consumers will be allowed always to use the ‘best’ ANP for each particular service instance.

Transition to UCWW and enabling the growth of CBM open opportunities to address these issues. The two principles underpinning this new CBM environment are: (i) the decoupling and separation of the administration and management of users’ AAA activity from the supply of a wireless access (transport) service and its devolution to new non-ANP trusted 3P-AAA entities, and (ii) the full consumer ownership and portability of their globally significant address.

Besides a range of new benefits for the consumer, UCWW has the clear potential to stimulate the creation of a number of new interesting business opportunities and to create a more liberal, more open and fairer wireless marketplace for existing and new ANPs. The primary ANP business success indicator will shift from subscriber numbers to the volume of consumer transactions – a radical change. This will increase the range of competitive price/performance and price/QoS offerings, specialist and niche access-network service offerings, and so forth, all of which will drive forward innovation in the mobile services market.

The preliminary blue-skies research work on crystallizing and defining the UCWW concepts and its key infrastructural pillars has been done already, e.g., (O’Droma, 2007) & (O’Droma, 2010). In-depth research, elaboration, design and implementation of these novel infrastructural components along with their integration into a pilot system prototype are the next phase of this project. The main goals are the following:

- Research, innovate, derive, design, implement, field-trial, validate and evaluate the performance of:
  - A feasible UCWW software architecture, operating within OSGi (Alliance, 2007) and cloud environments.
  - New UCWW infrastructural protocol interfaces and functionalities, especially for those on the 3P-AAA (Ganchev, 2006) and the third-party charging and billing (3P-C&B) (Jakab, 2011) service provision infrastructural elements, which satisfy and respect the network-independent, autonomous, trusted, and pervasive requirements and criteria of the service providers entities;
  - A prototype of the new universal CIM card employing the new ‘personal IPv6’ identity, (Ganchev, 2007) & (Ganchev, 2009).
- Design and establish the technological dimensions of the first scalable UCWW cloud-based system and provide a field-trial demonstration of its operation.
- On the back-end, design an UCWW cloud to facilitate the storage of user data harvested via mobile devices, and based on the analysis of this data, to offer predictions as to the applicability of services to particular users, and enable ever-enhanced contextualization and personalization functionalities and services. By monitoring this information, the system should accurately predict the types of services most applicable to individuals, and in turn, recommend these to the users. Furthermore, efficient heuristic algorithms must be designed to facilitate service utilization predictions locally on the mobile devices or as part of the UCWW cloud as an alternative to mining the stored data.
- Within the client devices, facilitate the effective functional design of the user profiles and GUI templates, targeted at the major smartphone platforms (Android, iOS, Windows Mobile), with each variation interoperating with the UCWW back-end cloud.
- Finally, making this UCWW cloud-based system commercially viable will be investigated. Clearly legacy mobile operators are likely to be reluctant to open their own customer profile database to competitors in whatever way that might happen; or not happen, as it is not in anyway essential to the proposal. UCWW cloud providers will market their services directly to consumers. In such a market, legacy providers would already be in prime position – to manage and market their own UCWW cloud services. Hence, the proposals in this paper could make the shift to UCWW more attractive for these operators. With such realization potency in mind, the deployment of service contextualization mechanisms will be investigated from an operator's point of view.

3 THE UCWW CLOUD AS A CONTEXT-AWARE MIDDLEWARE

From one point of view, the UCWW cloud that we envision can operate as a middleware of a context-aware system. In its traditional sense, a context-aware system is a distributed system, which consists of hardware devices (sensors) to sense or collect context data, applications which make use of this data, and middleware that manages the flow of context data from the points of collection to the applications. In our case mobile devices such as smartphones and tablet computers play the role both of the sensors of context data and the platform that runs applications which use this data. Besides the context that relates to the mobile *services* available and on offer, the context data may relate to the *user* (e.g., the user location, local time, current battery charge and other operational characteristics of the user's mobile device, etc.), and/or relate to the constraints of the wireless access *network* currently utilized by the user (e.g., QoS level and pricing scheme,), Figure 2.

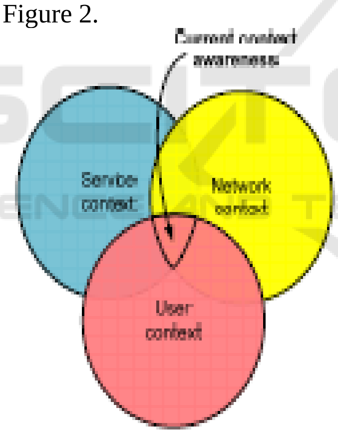

Figure 2: Context types and context awareness in UCWW.

According to the characterization of context-aware systems proposed in (Henricksen, 2005), the various functions and components of such systems can be organized into a five-layer architectural model, with layers (each providing services for the layer above it) as follows:

- *Layer 4*: Application components.
- *Layer 3*: Decision support tools/subsystem.
- *Layer 2*: Context repositories.
- *Layer 1*: Context processing components.
- *Layer 0*: Context sensors.

At the lowest layer, the mobile devices collect context data from the environment, and at the highest layer applications, which run on those mobile devices, make use of this data. Layers 1-3 form the middleware of the system, which can be entirely or partially implemented as cloud services. In particular, we propose layers 2 and 3 to be entirely implemented within the cloud, while layer 1 can be partially implemented at the mobile devices for increasing the overall efficiency of the system.

Surveys of context-aware middleware, (Henricksen, 2005) & (Romero, 2008), summarize the functional and non-functional requirements for a context-aware middleware. Besides the functions, already listed above (i.e., processing of context data, storing context data in repositories, and providing decision support tools), a context-aware middleware may also be expected to address the following issues:

- *Heterogeneity*: In our particular case, this means to support a variety of mobile devices and operating systems.
- *Adaptation*: In order to adapt to the user's habits, the system needs to perceive the context of the environment (via sensors) and quickly react and adapt to changes in the context. This is particularly important for our system because we expect frequent and constant changes in the context due to the mobile nature of the user devices (sensors).
- *Scalability*: The performance of the system when interacting with a large number of users should be on the same scale as when interacting with a small number of users. In a typical scenario, there could be a few thousands of sensors at a site (e.g., a large airport) and potentially millions of users at various sites who simultaneously query the decision support subsystem (c.f. the query configuration in Figure 3).
- *Privacy*: The privacy of the users' data must be maintained according to their preferences. Levels of confidentiality, options in regard to this, and distribution of responsibility are challenging issues in this context.
- *Traceability and control*: Users should be able to control any automatic functions of the system and the systems should provide means of making those decisions transparent to users.
- *Application building support*: It is also essential for our system to provide application programming interfaces (APIs), which enable software developers to build a variety of smartphone applications which interact with the context-aware middleware.
- *Easy deployment and configuration.*
- *Tolerance to component faults.*

There have been a few generic context-aware middleware solutions proposed in the research literature, including Gaia (Román, 2002), Reconfigurable Context-Sensitive Middleware (RCSM) (Yau, 2002), PACE (Henricksen, 2005), CARISMA (Capra, 2003). While using these as a base for comparison, we propose to design a cloud which provides the features expected from a context-aware middleware and at the same time is highly specialized for the particular nature of the UCWW.

Furthermore, we consider a concept of context which allows the decision support subsystem to make smart decisions based on mining of data stored in the cloud repositories. We propose the context to include both the data sensed by the sensors in the environment (as in a typical context-aware system), and the history of the user and the collective history of users who have used the system in the same environment. To the best of our knowledge, this is a novel approach in providing context-aware services with elements of personalized information retrieval (PIR) in a mobile network environment.

Extension of the UCWW cloud's functionality is also envisaged which will open opportunities for trusted third-party communication service providers (Toseef, 2011). These will negotiate with providers on behalf of users for their service requests and they may assist in handling seamless handovers to ensure uninterrupted service delivery to users.

4. DECISION SUPPORT SUBSYSTEM

Figure 3 summarizes the flow of context data between a smart mobile device and the UCWW cloud as well as the mechanism of sending requests and receiving responses from the decision support subsystem. The role of the decision support subsystem is to provide ratings (ranking) of the service providers available for particular type of service requested by the user. In order to make accurate predictions, the decision support system makes use of additional context data, which may include any of the following:

- User-specified parameters such as the upper bound on the price, lower bound on QoS, etc.;
- Current user location, current time, battery charge and potentially other parameters of the environment;
- The request and decision history of the user who is requesting the decision;
- The request and decision history of users who have requested the same service in the same or similar context.
- 'User-unaware' context autonomous cloud functionality, including new wireless services of which a user(s) may be totally unaware but may likely prefer as a replacement for existing services. An example could be the vast array of government services coming down the line, e.g., G-Cloud in the UK (c.f. gcloud.civilservice.gov.uk).

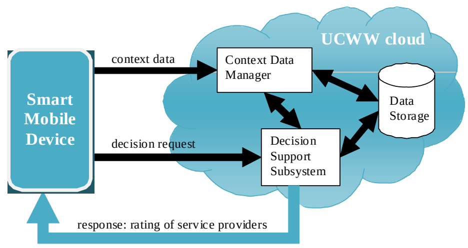

Figure 3: Communication between a smart mobile device and the UCWW cloud.

Context data can be sent from the mobile device to the cloud either together with the request for decision or asynchronously when changes in the context occur. Any context data gets processed by the context data manager which prepares the data for storage and makes changes to the data storage. When a request for a decision arrives, it is accepted by the decision support subsystem, which in turn requests the current context from the context data manager before making a decision. After a decision is made, the decision support subsystem notifies the context data manager so that the decision can be stored in the data storage. In accordance with the requirements listed in the previous section, the decision support subsystem may also accept requests to explain its decision. In satisfying such requests, it is assisted by the context data manager, which can provide the correct historic information that was used in making the decision. Such mechanisms would also serve service auditing processes, service level agreements, etc.

Systems which retrieve information that is both relevant to the submitted queries and personalized for the user are known as PIR systems. They have been the subject of extensive research in the last couple of decades with a major application in web search as well as in other areas such as eLearning and news dissemination (Ghorab, 2012). A community-based PIR (Teevan, 2009) & (Sugiyama, 2004) would suit our needs best because ideally we would like to offer personalized results to the user based on their previous behaviour and experience but also based on the experience of other users who have used the service in a similar context. An early research action is to decide what information about users should be tracked, how this information will be gathered and stored in a user model and then how user models will be used for retrieving personalized results.

In summary, we propose to build the data repository according to existing models employed for community-based PIR. The decision support subsystem will be tuned by experimenting with a variety of data mining algorithms (Witten, 2011) and finding an acceptable compromise between speed and accuracy of the predicted rating of providers. Once the decision support subsystem's software tool can make accurate predictions – whether by running heuristic algorithms for solving optimization problems (Papadimitriou, 1998) locally on the smart mobile device or by using a service provided by the cloud, or a combination of both –, these predictions can be delivered to the application level and incorporated into the client's GUI, aiding the user in making a choice for a particular service or, where the user so desires, configuring the system to make automatic choices.

5 IMPLEMENTATION ISSUES

While UCWW is a completely distributed wireless communications environment as described earlier, one could conceptually consider the software underpinning its various infrastructural elements within a conceptual software architectural model. This may help facilitate comprehensive, systematic, organized and managed software designs and solutions, with a view also towards increasing software re-use. Hence below a speculative 3-tier architecture model is suggested (Figure 4).

5.1 UCWW software architecture model

The 3-tier UCWW software architecture model typically would include, at the application tier level, such key elements as the 3P-AAA/3P-C&B applications, the CIM card, a multi-agent platform, and a Hadoop cloud environment (Borthakur, 2007).

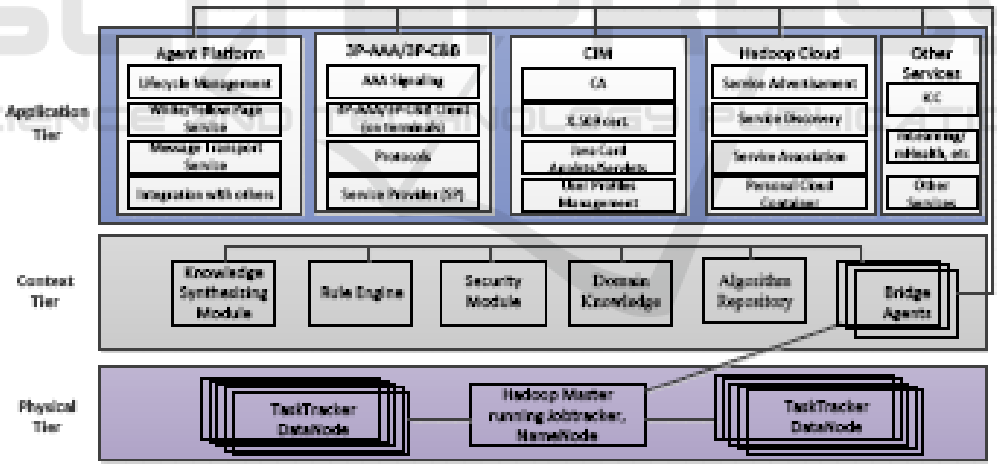

Figure 4: The UCWW software architecture model.

The UCWW middleware is being developed with three clusters, namely Kafka (kafka.apache.org), Storm (storm-project.net), and Hadoop HDFS (Figures 5 & 6). Kafka is a high-throughput distributed messaging system, used as a load balancing cluster for parallel data loading into Hadoop. The data output from Kafka is sent to the Storm cluster for real-time processing. Then the useful dataset is serialized to HBase in the Hadoop cluster. The Hive (hive.apache.org), Cloudera Impala (ccp.cloudera.com), and Flume (flume.apache.org) will be used for data mining.

5.2 3P-AAA/3P-C&B

Based on the 3P-AAA/3P-C&B infrastructure, an amendment to ITU-T's SBM authentication architecture for interworking in NGN is being designed, developed and implemented (O'Droma, 2008), based on the ITU-T Draft Rec. Q.3202.1

(ITU-T, 2008) SBM 3P-AAA model. A JDiameter (JDiameter, 2013) based 3P-AAA framework is being realized. The 3P-AAA/3P-C&B platform will be realized in a lab environment with corresponding mix of client applications for smartphones.

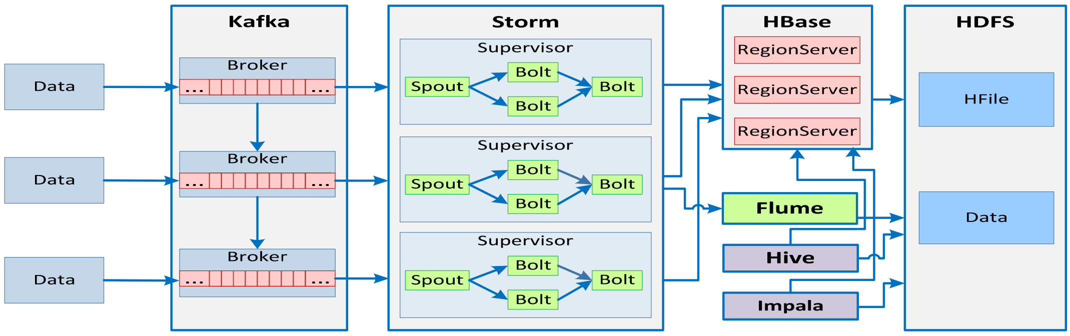

Figure 5: The UCWW middleware.

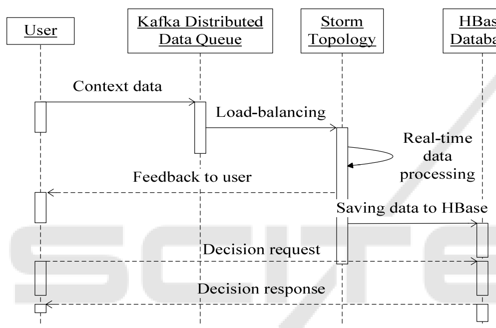

Figure 6: Context data processing in the UCWW middleware.

5.3 CIM

The universal CIM card acts as a user data server in the UCWW system. A number of security applications run on a single virtual machine to maintain the user profiles, associated credit-card information, user's personal IPv6 address, 3P-AAA/3P-C&B related data, X.509 certification, personal cloud container, etc., and ROM and EEPROM on the CIM card. These applications will communicate with each other using shared interface objects (SIO), (Avvenuti, 2012). A firewall is defined by each application to provide application-level security.

A personal cloud container is being designed to include a UCWW personal cloud identifier, personal data category, session ID, cookies, etc. The client application is being developed to work within a Google Android (Fledel, 2012) environment (Figure 7). A SIMAlliance Open Mobile API specification (SIMAlliance, 2013) will be integrated into the Android platform to enable user devices to communicate with secure elements of the CIM.

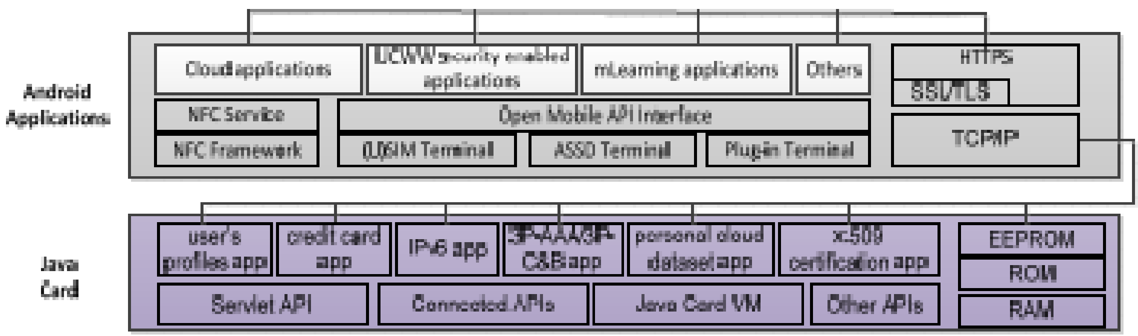

Figure 7. The CIM module on Android.

6 CONCLUSIONS AND FUTURE WORK

The UCWW infrastructural entities and protocols are all novel. Hence also all of the work on this project is innovative and advancing knowledge in the area. Our work will show that this completely original way of organizing the global mobile telecoms business is feasible. The innovative infrastructural and technological changes to be realized in the pilot field trial will demonstrate how UCWW will enable greater service choice, contextualization and management capabilities for consumers, much more openness in the wireless access market for the supply of mobile services, and a technologically friendly environment for the incorporation of new and revolutionary ideas in wireless communications. It will demonstrate for instance, the inherent full number-portability and the disappearance of roaming charges. The work will yield foundational contributions to global NGN standardization work within ITU-T's Future Networks workgroup.

The UCWW is a big undertaking with huge and complex international socio-economic implications for the wireless communications business, and encompassing the present and future rapid growth of wireless communications and cloud-based computing technologies. Our aim is to design a context-aware middleware for the UCWW by having most of its functions offered as cloud services and the rest running locally on mobile devices. In addition, we plan to create a set of sample GUIs, which possess the necessary intelligence to harvest the requisite information to facilitate service predictions (Raskin, 2000). The design and development of an efficient context-aware middleware for the UCWW cloud requires taking into account a number of aspects:

- On the back-end, the designed UCWW cloud must facilitate the storage of data harvested via mobile devices, and based on the analysis of this data, offer predictions as to the applicability and ABC&S suitability of services to particular users. Over time the data collected relating to particular users can give an accurate view of particular cohorts, based on common interests, repetitive access of particular services, etc. By monitoring this information, the system can accurately predict the types of services most applicable to individuals, and in turn, recommend these to the users. Furthermore, efficient heuristic algorithms must be investigated to facilitate service utilization predictions locally on the mobile devices or as part of the UCWW cloud as an alternative to mining the stored data.
- The option of this UCWW cloud collaboration with wireless billboard channel (WBC) service providers (Flynn, 2006) holds potential. Through it, consumers may have their UCWW cloud distilled information, relevant to their particular (or upcoming) location and time, delivered to them in a personalized frame through an appropriate WBC.
- Within the client devices, an effective functional design of the GUI must be facilitated. With this in mind, different mobile platforms will be targeted, particularly in the case of the smartphones market, where Android-based devices, iPhones, Windows phones etc. each have a market share.

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