Session and Network Support for Autonomous Context-Aware Multiparty Communications in Heterogeneous Mobile Systems

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ABSTRACT

The increase of networking complexity requires the design of new performance optimization schemes for delivering different types of sessions to users under different conditions. In this regard, special attention is given to multi-homed environments, where mobile devices cross areas with overlapping access technologies (Wi-Fi, 3G, WiMax). In such a scenario, efficient multiparty delivery depends upon the grouping operation, which must be done based on several parameters. In this paper, the authors propose context-aware sub-grouping of content-based service groups so that the same service session can be delivered using different codings of the same content, adapting to current network, users, session, and environment context. The context-aware information is used to improve the sub-grouping process. This paper aims to describe these sub-grouping techniques, and in particular how they improve network performance and user experience in the future Internet by focusing on the improved network-level and session-level mechanisms.

Keywords: Context-Awareness, Heterogeneous Mobile Systems, Multiparty Communications, Network Management, Session Management, Telecommunications Technology

DOI: 10.4018/jhcr.2010100101
INTRODUCTION

Increasing demands in group-based multimedia sessions, new technologies and market forces are fuelling the design of the future Internet, which is expected to fundamentally change the networking landscape in the upcoming years. In order to preserve profitability while increasing revenues, network/service providers must optimize costs and provide new types of sessions operating in a mixture of access technologies (wired and wireless), which is not trivial and demand complex control. Special attention must be given towards group-based multimedia sessions, since the strong requirements on Quality of Service (QoS) must be fulfilled simultaneously for all users of the same group and be kept during the entire session lifetime.

In terms of group-based sessions, efficiency of session setup requires a correct definition of user groups. Nowadays, most mobile devices are produced with multi-homed capabilities, and it is common to cross areas where there exists overlapping of different network access technologies, such as Wi-Fi, 3G and WiMax. The efficiency of the grouping operation (creation of a set of users to receive a given session) may depend on a few parameters, including the access technology. For instance, 3G networks have lower bandwidth capabilities in comparison to Wi-Fi and WiMax networks, thus, depending on network conditions, for 3G users to be able to join a session, capacities should be carefully considered. Thus, sub-grouping could be performed and the same service session could be delivered with different throughput (e.g., using different codings of the same content) to adapt the throughput to the current network capabilities. In addition to network traffic, other types of context information should also be used to improve sub-grouping, such as noise, terminal location and speed, user’s priority and network preferences, user’s terminal capabilities, quality of signal strength received, environmental conditions etc. Moreover, history context information can also be used for improving sub-grouping. For example, previously received context can be compared with current context for patterns to be located. Using some intelligence, forecasts of undesirable events are possible and sub-groups may be created so that such events are avoided.

The paper, based on work performed in (PT Inovacao, n.d.), proposes such innovative sub-grouping process to enable context-awareness and consequently self-optimization in multiparty, converged mobile environments. These sub-grouping techniques, and in particular how they improve network performance in the future Internet, are described in the scope of cognitive self-managed networks. The session and network-level grouping processes proposed in this paper take as a base support, the description of the base functionalities of each element in the architecture, described in (Antoniou, Christophorou, Neto, Sargento, Pinto, Carapeto, Mota, Simoes, & Pitsillides, 2009), going further on the complete framework for multi-level context-aware sub-grouping. In (Antoniou, Christophorou, Janneteau, Kelil, Sargento, Neto, Pinto, Carapeto, & Simoes, 2009) it was presented a first attempt on the support of context-aware sub-grouping. In this paper, it is provided a thorough description of the sub-grouping mechanism and a full solution for its support, including how session modification and network selection are handled and how they impact sub-grouping. Moreover, we provide information on how such a framework is implemented and evaluated.

Related work is briefly presented next, followed by an overview section discussing a context-aware multicasting architecture and introducing the sub-grouping mechanism. The following two sections diverge into the self-management through sub-grouping as designed at the session and network layers. A presentation of how context is used by the content comes next, and finally the last section offers conclusions and directions for future work.

Related Work

The increased popularity of multimedia group communications requires that evolved session management functional entities be able to
provide rich-media content to mobile communities in an effective way. In Amran and Fuchs (2006), Zafar (2006), Antoniou (2007), and Zafar (2008), a converged, multi-bearer service architecture that supports broadcast and multicast services was defined. Context information was used as input for service group creation influencing the formation of multimedia sessions. Enhanced signaling procedures for an effective IMS and MBMS integration were presented in (Pinto, Knappmeyer, & Al-Hezmi, 2008) supporting the provisioning of multimedia sessions to mobile communities using unicast, multicast and broadcast bearers. In (Al-Hezmi, Magedanz, Pallares, & Riede, 2008), architecture for IPTV services is proposed over IMS-based NGN networks enabling the delivery of converged multimedia services over unicast, multicast, and broadcast transmission modes following the approaches from ITU-T and TISPAN. A hierarchical group management framework is proposed in Zafar, Fuchs, and Baker (2008) enabling management of transcoding based groups. It is demonstrated that there is an advantage for using more efficient codecs, by subgrouping multicast groups based on supported codec, as they become widely available in the network. Thus, in Handorean, Sen, Hackmann, and Gruia-Catalin (2005) strategies are exploited, which involve the use of contextual information, strong process migration, context-sensitive binding, and location agnostic communication protocols for “follow-me” sessions. Finally, in Antoniou, Riede, Pinto, and Pitsillides (2009) the session management functionality is extended for multiparty sessions to consider context triggers in the creation, modification and teardown of sessions. With the proposed enhanced session manager, multiparty content distribution will be done in the most efficient way, resulting in new “personalized” sessions.

In next generation networks, multiple access networks will coexist, therefore, an access selection process, using algorithms based on context, preferences and capabilities, should be in place to enable the optimization of both terminal and network (Jesus, Sargento, & Aguiar, 2008).

Paradigms where hosts have access to multiple networks are not new: multi-homing is used to improve resilience, dependability and performance. However, multi-access network selection is currently rudimentary and automation is not usual. However dynamic network access selection, considering QoS requirements and instantaneous context is not yet possible in real networks; currently in 3GPP there are standardization efforts on multi-access network connectivity. As currently specified by 3GPP in (3GPP, 2006; 3GPP, 2009), two modes of operation are supported; Automatic and Manual. In automatic network selection mode the mobile terminal automatically uses a set of rules to find the network to register with. In manual network selection mode, the mobile terminal displays a list of available networks to the user. The user selects one of them and the mobile terminal attempts registration onto that network. If the registration is not successful, the mobile terminal shows the list of networks to the user once again. In manual mode, the user selects a particular network with no or few information about the available networks.

From the surveyed papers, many schemes have been proposed to perform network access selection in a wireless heterogeneous network environment. In Tolli, Hakali, and Holma (2002) load balancing is used with a predetermined load threshold which if exceeded a handover (either vertical or horizontal) is triggered. In Taha, Hassanein, and Mouftah (2000), when the capacity of the existing RAT is full, it vertically handovers existing users into another overlaid RAT that has the same cell-coverage in order to obtain resources for newly entering users in the current RAT. In Taha, Hassanein, and Mouftah (2000), when the capacity of the existing RAT is full, it vertically handovers existing users into another overlaid RAT that has the same cell-coverage in order to obtain resources for newly entering users in the current RAT. In Romero, Sallent, Agusti, and Diaz-Guerra (2005) the RAT is selected by considering the RAT characteristics (i.e., coverage, capacity, etc). Other schemes proposed to address efficient RAT selection are
namely the Consumer Surplus (Ormond, Perry, & Murphy, 2005), the Profit function (Liu, Li, & Zhang, 2006), and Game Theory (Niyato & Hossain, 2006). Many other proposals base the decision process on radio signal properties; however this is only one of the many criteria in such selection schemes. Thus, some proposals suggest context-aware decisions (Jesus, Sargento, & Aguiar, 2008). Moreover, the majority of related work focuses entirely on network selection algorithms, not concerning other important mechanisms crucial to support the decisions, e.g., QoS management, to enable the complete network re-configuration triggered by context. In this paper, we consider the support of context-aware network access selection, in a multicast environment, where the group membership is a main issue, but being flexible enough to support any parameter envisioned. Intelligence and context-awareness is integrated in our algorithm facilitating it to be autonomous, self-adaptable and self-controlled. By considering the instantaneous context of the users and the network’s, the intelligence integrated in the algorithm predicts trends in users’ and network’s behaviour and dynamically adapts the network access selection thresholds and the algorithm’s operations to any situation, aiming to provide the end users with seamless service continuity and best possible QoS while at the same time use as less radio resources as possible and avoid any undesirable event that can influence the network performance (like congestion, overloading, QoS degradation, etc.) or the quality experienced by the users (i.e., call drop, QoS degradation, etc.). Thus, the main objective of our algorithm is to benefit the users and the Network Operators, alike.

On the session layer, most of the solutions proposed use the Session Initiation Protocol (SIP) as main signaling protocol on IP networks. Much effort has been put recently on the autonomic network concepts (Antoniou, Christophorou, Neto, Sargento, Pinto, Carapeto, Mota, Simoes, & Pitsillides, 2009), where autonomic processes can perceive network conditions, plan, decide, and act on these conditions. They can learn from the impact of former adaptations and accordingly make future decisions, while considering end-to-end goals. Autonomic networks are promising for wireless networks, which are highly dynamic and complex to manage. Our approach is towards the autonomic concept by enabling the dynamic optimization of the use of the network taking into account also the history and instantaneous context of the users, network, sessions and environment. This is manifested through an appropriately designed architecture that efficiently allows context-aware, multiparty delivery, as described in (Antoniou, Christophorou, Janneetate, Kelil, Sargento, Neto, Pinto, Carapeto, & Simoes, 2009).

**CONTEXT-AWARE MULTIPARTY SERVICE PROVISION**

This section presents the overall context-aware multiparty architecture, able to support context from the user, network, sessions and surrounding environment in future multiparty mobile communications. We also show how the context can influence grouping and sub-grouping of users at different levels from the environment and user-levels, to the session and network-layers.

**System Architecture**

Figure 1 depicts the context-aware multiparty reference architecture. It aims at providing an end-to-end context-aware communication framework specifically for intelligent multicast/broadcast services. The three main parts comprise: the context and group management service enablers, with reasoning and grouping users based on context; content adaptation and delivery based on context; and context information collection through sensors, context distribution and context aware multiparty transport.

In this paper we focus on the multiparty delivery layers and how they support session delivery through efficient network mechanisms, both supporting context information and grouping/sub-grouping of users based on the different sources of context information. In the following paragraphs we briefly describe the main
entities of the multiparty delivery process and we subsequently focus the description on the session and network interactions.

**Context Providers (CxP)** – These entities obtain contexts from sensors and networks, map them to information in an interpretable manner and deliver this information to the several components.

**IP Transport (IPT)** – This entity controls the integrated QoS and IP multicast enforcement in the nodes along a communication path for the efficient delivery of multiparty sessions to groups of users with QoS-guaranteed over the time. Moreover, IPT is able to dynamically build delivery trees in heterogeneous environments. The performance limitations of existing proposals motivated the design of IPT with support to distributed per-class resource control. For scalability, network edges coordinate resource allocations and interior routers remain simple, by reacting only upon both signaling and network dynamic events (e.g., link failures, re-routing or mobility), where these events can be local or triggered by context changes.

**Multiparty Transport Overlay (MTO)** – This functional entity provides a generic, scalable, and efficient transport service for group communications by applying the overlay paradigm at the transport layer. It hides the heterogeneity of underlying networks in terms of IP multicast capabilities or IPv4/IPv6 support, enabling the dynamic creation of an overlay tree at the transport level, between the source and the group members.

**Network Management (NM)** – This functional entity performs context-aware decision of the best connection of multimode terminals in heterogeneous networks. It makes use of user, environment, network, and session context, to drive intelligent network selection, in terms of communication path, terminal interface and access technologies. Moreover, it is expected to achieve more efficient resource utilization, as well as more uniform distribution of data load, while fulfilling the QoS required by sessions and experienced by the
users. For instance, the Wi-Fi incoming interface of a terminal should be changed to the WiMax during congestion periods, or after terminal mobility to an area without Wi-Fi coverage area. In addition, the NM, associated with MTO, allows generalized transport by assigning MTO trees and controlling packet transport along them. Thus, end-to-end multiparty content transport over network segments with different transport technologies (i.e., unicast and multicast) is deployed with context-driven, scalable self-organization and seamless resilience support.

Session Management (SM) – This entity manages user-to-content and content-to-user relationships, through session control. It is intelligently designed to enable the use of context information for session control, using the SIP, in terms of network-specific, environment-specific and user-specific contexts, without in fact knowing the actual network, environment or service details through Session Management Enabler (SME) and Session Use Management (SUM).

Mobility Controller – This entity applies the decisions issued by the NM related to the network interface to be used in the terminal, for vertical handover decisions.

Concerning session and network interactions and context-aware support, the following paragraphs detail the interactions and functionality of both SM and NM.

SM interacts with network modules to require transmission quality specifications, ensuring that the network has enough resources to make the transmission effective without quality loss. For this requirement the SM needs to know the capabilities of the access network assigned to a user, a task undertaken by the NM. The SM also considers context information, e.g. user profile and preferences, terminal capabilities e.g. in term of codec support, to choose the correct parameters for the session, such as media codecs and video display resolution, and to perform groups of users according to the context parameters. Overall, SM participates in dynamic changes such as switching between different contents.

NM then receives from the SM different parameters, including session ID code (with QoS requirements in terms of maximum throughput and tolerance to delay, loss and jitter) and user ID list, where NM uses the latter to retrieve context of each user from a Context Broker (CxB in Figure 1). Based on instantaneous user and network context, NM selects the best wireless network interface and proposes initial sub-grouping of users accordingly. Afterwards, NM matches in a local database (carrying overall network topology) the best overlay nodes (the edge nodes of the MTO trees) that will be part of the MTO Tree for each sub-group. In addition, it triggers IPT to select the best communication path (multicast or unicast) between these overlay nodes and further enforces both QoS (per-class bandwidth reservations) and, if applicable, IP multicast (IP multicast address allocation, Multicast Routing Information Base (MRIB) population and multicast routing protocol triggering at the egress overlay nodes). After succeeding, IPT triggers MTO with the IP multicast addresses of multicast MTO branches to MTO component, allowing MTO to create multiparty transport connections and start multiparty data delivery. When all these processes are successful, SM is triggered to resume session setup.

Context-Based Sub-Grouping

In this context-aware architecture, grouping and sub-grouping of users in the same session does not only depend on the desired content (performed at the Service and Application levels), but also, due to the variety of context information, it is also performed at Session and Network levels, supported by the session-related and network-related context. As an example of session-related context, based on availability of codecs support in the terminals, users may need to be sub-grouped in different sessions with different codecs but with the same content. As an example of network-related context, due to
the context information, the best access technologies for the users in the same group may be different, since user context and environment is also taken into account. The different networks may have different guarantees, which may require the content to be delivered with different quality and codecs, hence requiring users sub-grouping.

The Session Management is the element that accepts context information through requests or triggers and answers by creating/modifying/terminating the sub-group sessions. Once it determines the matching between available content formats and user capabilities in terms of supported content formats, resulting in candidate files per user in the service group, it is responsible of first inviting the users to a session and to invite the content provider to deliver the content to these users.

When some context changes, and this change is relevant to the way the service is consumed, the session management should be capable of adapting the user’s session accordingly (move a user to a different sub-group, or eventually create or delete sub-groups). The trigger can have different sources (network conditions change, device change, handovers, etc).

The Session Management should be able to notify the Network Management to modify sub-groups/sessions based on the above notifications. This might make the Session Management terminate the SIP and Media session both with the client and the content provider. It should also be able to modify sessions based on notifications coming from other components, through changes in context. According to the trigger, when only sub-groups are affected, it is important to modify the multiparty session as well. Therefore, it will communicate all changes to the Network Management to adapt the trees (and the correspondent overlays) accordingly, and possibly change the network and technology to the new sub-groups.

On the network side, each of the created sub-groups represents a multicast delivery tree or, in case of a single user, a unicast connection, that requires network resources. The Network Context Provider improves the network operator view about network resource usage, to optimize network resource management and QoS. It is then possible for the network to provide different QoS levels to the members of a group that consume identical content, but experience various network contexts. This is the process of network level sub-grouping.

The Network Management is triggered through network level context, or by the Session Management to adapt the network and users in the network. It performs an optimization process whose output is the decision of the networks/technologies to be used and the content coding that will be received by the several users. If the users in the same group change the attached network, and the levels of QoS cannot be fulfilled in the networks of a group, sub-grouping is performed at network level, and different QoS, and possibly different codecs, will be assigned to the different subgroups. For some cases, where not all the users or links have the required multicast capabilities, overlay nodes are enabled to abstract the grouping decision of these considerations. Moreover the sub-grouping flexibility allows, for instance, in the same session, two users to receive the same audio, but different video streams with different codecs or rates, just depending on the available resources or preferences. In this case both would be in the same audio sub-group, but in different video sub-groups.

The following two sections will describe in detail the context-aware sub-grouping processes, both at the session and network levels.

**ENABLING CONTEXT-AWARENESS AT THE SESSION LEVEL**

**Session Management Overview**

Session Management is the entity in the core of a multicast-enabled, converged mobile architecture that provides the necessary signaling to deliver a specific content to its consumers and can handle different types of events regarding session control. Context-aware Session Management is a key functionality of a heteroge-
neous mobile system. Specifically, the session management deals with context that is relevant in order to select the right content for its consumers. Therefore, the first step for enabling context-awareness in the multicast-enabled, converged network is to recognize and use content-related context. Such context may be categorized as Device Context (e.g., supported coding options) and User Context (e.g., user preferences). Thus, the Session Management entity will be able to recognize context triggers, as well as be able to make additional requests for context when necessary to the appropriate functional entity within the system architecture.

**Context-Aware Session Management**

The context-awareness in the Session Management entity comes from the recognition of context as triggers or the capability to receive any context requested, e.g., for initiating a context-aware session. Therefore, the Session Management entity has the functionalities described in the subsequent paragraphs (based on interfaces with other system functional entities), necessary to enable this awareness of context information.

Primarily, the Session Management needs to interact with the entity responsible for identifying the service groups, i.e., the groups of users that will receive the same content. Through this interface the Session Management must receive identification for the service group, together with separate identifications for the individual users that comprise the particular group.

Consequently, the Session Management must be able to interact with the entity responsible for Content Processing and Delivery. The Session Management sends the group identification received in the step described above, to the Content Processing and Delivery entity, and the identification is used by this entity to collect some general content information for the group, e.g., whether the content that will be received by the particular group is video or audio, as well as some more specific information, e.g., the coding(s) and bitrate(s) in which the particular content is available. Thus, the Session Management entity acquires descriptive information on the content that will be transmitted to the group.

Once the content description has been acquired, the Session Management needs to check which of the available content codings the users are capable (device context) and willing (user context) to support. Device and User context information is collected at a broker system entity, i.e., an entity in the converged architecture that accumulates all context information received from various context producing entities (for instance the user terminals in this case). The Context Broker entity contains the required device and user context, therefore the Session Management entity requests for each user in the service group its capabilities and preferences, including coding options supported/preferred by the user device (e.g., resolution, coding options supported).

Once this particular context information is obtained per user, the Session Management entity can match the content codings/formats in which the content is available, i.e., received from the Content Processing and Delivery (CtPD) entity, to the content codings/formats that each of the group users is capable or willing to support. This matching results in a list of particular content codings per each user, which may be viewed as an initial refinement of the original service group to sub-groups of users according to the supported content. This is the first step of the sub-grouping process. The sub-grouping will continue in the network where further refinements will additionally consider network and environment context (e.g., current QoS capabilities based on user location and current network load).

The sub-grouping is initiated in the Session Management entity but is further refined and concluded in the Network Management entity, since network and environment context are more appropriately collected at that system level. Consequently, the Session Management entity must support interface functionality to exchange information with the Network Management entity. Over this interface the Session
Management entity will send the list of users and their supported content codings (once the matching of content availabilities and content capabilities is performed), and will receive the finalized context-based sub-grouping of the original service group by which only one content coding will be selected for each user in the original service group. This will enable a context-aware session for each multicast sub-group to be setup.

**Initiating a Context-Aware Session**

In this section, we describe the session initiation by focusing on the Session Management functionalities as described above. In the subsequent discussion, the Session Management functional entity is separated in two functional modules: The Session Management Enabler (SME) and the Session Use Management (SUM). In terms of functionality the SME is the Session Management functional module that accepts context information through requests or triggers and responds by creating/modifying/terminating the sub-group sessions. In other words, it handles the interfaces between the SME and the entity providing the identification of the original service groups, the entity responsible for matching a group context to the appropriate content, the SME and Network Management, the entity that knows the network, the SME and the Context Broker entity, where all context information subsides, as well as the SME and CtPD, the content processing and delivery entity. Finally, the SME needs to interact with the SUM, which is the sub-module responsible for handling the SIP-specific tasks of the Session Manager, such as inviting the users and the Media Delivery Function to sessions. Once the Core Entity of the SME determines the matching between available content formats and user capabilities in terms of supporting content formats, resulting in candidate files per user in the service group, SUM takes over, which is responsible of first inviting the users to a session and to invite the CtPD to deliver the content to these users.

Figure 2 illustrates the messages exchanged during session initiation that are relevant to Session Management (both the SME and SUM). SME receives group identification and immediately requests group content information from the CtPD. For each group user the terminal capabilities and user preferences are collected from the Context Management System and particularly from the Context Broker entity. The matching between this information results in a list of users and corresponding available content codings, which is sent to the Network Management to proceed with more refined sub-grouping. The returned user list has one coding per user, with all users that support the same content coding to form a subgroup. Then, the SME interacts with the SUM to open a new session for each subgroup by inviting the users that belong to that sub-group to join the session, and by inviting the Media Delivery function (part of the CtPD) to deliver the particular content coding for that sub-group.

**MODIFICATION OF A CONTEXT-AWARE SESSION TRIGGERED BY CONTEXT CHANGE**

The Session Management is capable of adapting itself and the existing sessions whenever there is a trigger containing a new context that requires the session to be updated to a new state. This trigger can come spontaneously from another component (such as Network Management) or can derive from previously subscribed context information. In case the Network Management is involved, all the resource reservation must be reconfigured. Figure 3 shows the interaction between the involved entities.

Specifically, session modification when new context information is available (Figure 3) is achieved in the following manner:

**Step 1:** The SME is triggered with the information that a particular user is suffering from network congestion (previously
subscribed to this context). According to the existing sub-groups, it decides to downgrade the user to another sub-group containing the same media files but coded in a lower bitrate version. Optionally, it can inform the NM to reconfigure the overlay tree and QoS settings accordingly. We are also assuming that the newly decided sub-group media type was already setup for the current group.

Step 2: When all decisions are taken, the SME sends a SIP INVITE (through the SUM) message towards the involved user, containing the new multicast address to join.

Step 3: Before joining the new multicast address, the user leaves the previously joined address.

Steps 4 and 5: The user joins the new multicast address and informs the SME that the process went without any problems. At this point in time, the user should be receiving the new low bitrate media stream (B instead of A).

ENABLING CONTEXT AWARENESS AT THE NETWORK LEVEL

Network Management Overview

The Network Management (NM) component is the element that provides intelligent end-to-end path and network selection. This is achieved by considering user, network and environment context, allowing terminals to be always best connected and receive content over multiparty sessions while benefiting from satisfactory Quality of Experience (QoE). It takes advantage of diverse context information obtained from multiple sources and allows multimode terminals to be always “best” connected. By making use of context, NM successfully drives
intelligent network optimization, be it in terms of communication path, terminal interfaces or access technologies selection. NM assumes complex, dynamic and heterogeneous scenarios, where network events (link failures, handovers and traffic conditions) take place randomly over time. Such network dynamism and complexity requires a new concept of network architecture in order to efficiently support management of users in sub-groups. Similarly to the way SM is separated into the functional entities SME and SUM, the NM is separated in the Network Management Enabler (NME) and the Network Use Management (NUM).

**Context-Aware Network Management**

This section describes in detail the NM by elaborating separately on the NME and the NUM, specifically on their functionalities and roles in terms of context usage and sub-grouping.

The NME is the module that enables network support and provides the interface with the SME and the upper layers. It has the main responsibility of sorting out network level groups. Actually it divides the service groups into smaller sub-groups according to the quality on the stream they will be receiving, based on the user, the network, the operator policies, and a large set of context information. NME can be triggered and receive requests from the Session Management, concerning resource setup, modification and teardown, i.e., service groups are refined according to content availabilities matched with user capabilities. After a session request, NUM is triggered to execute the network selection process of an intelligent access technology (using network, user and environment context dynamically obtained). Furthermore, it also requests NUM for the selection of possible near-optimal multiparty communication paths, (multicast and/or unicast) which can provide sufficient resources.
throughout the network and support the network interfaces. At this point, and with the possible end-to-end communication paths, the best network interfaces, the user and operator preferences plus a set of diverse context information, NME divides the users into different sub-groups. This whole process can be extended with new sets of context information that can be used to better refine sub-grouping. This way, each specific unicast/multicast subgroup will reflect a unique (to that content) quality of service. In addition, these mechanisms were defined to cope with modifications due to network problems or context changes. Once the sub-groups are created and provisioned by the underlying modules, this information is returned to the Session Management entity with the respective IP addresses and ports and selected content coding for each sub-group.

The NUM is essentially the module responsible for managing network resource allocation functions, for the whole end-to-end path, access, aggregation, and core networks. It encompasses the network selection, aiming at providing intelligent Radio Access Technology (RAT) selection based on context-aware information to groups of users, as well as selection of communication paths, which is done based on network information. The network selection function deploys intelligent context-aware RAT selection for the users of a group, both at the session setup and also periodically during the session. NUM, by taking into account current networking and environment user context (i.e., noise, interference, RATs within reach, signal strength received, signal strength alteration rate, terminal’s capabilities, user’s preferences, etc.), as well as the current network context (i.e. QoS capabilities of RATs, available capacity and current load in RATs, etc.), selects the RAT that will serve each user and the content coding that each user will receive in such a way that enhanced capacity and network performance is achieved. Upon selecting the RAT and content coding for each user, NUM triggers the NME to control the network resources, also informing each terminal about the selected interface from which multiparty content will be provided (i.e., Wi-Fi, WiMAX, UMTS, LTE, DVB, etc.). The network selection process also provides support during the multiparty sessions transport, i.e., users of on-going sessions can receive multiparty content from a different network interface, due to changing network conditions or even vertical handovers (with the support of the Mobility Controller (MoC) installed in the Terminal).

NUM is also responsible for selecting the best communication path within the network. It receives requests from the NME to decide on the best path for the multiparty connection. To do that, NUM maps the QoS requirement of the multiparty session into an available class of service, also taking into account all the network status when selecting the path. In this sense, it deploys admission control operations along the network communication path. Afterwards, it returns them to the NME, which finally takes the decision of enforcing the reservation. Consequently, NUM receives the enforcement order and commits the resource reservation by triggering each router to enforce both QoS and multicast. QoS enforcement consists of indicating the amount of bandwidth and class of service for resource reservation, and Multicast enforcement comprises of populating the MRIB with the information about nodes of the selected path. At the end, NME is informed about the success of the operation.

**Grouping as a Part of Network Management**

Whenever SME triggers NME with a new request, it contains the users that were selected to receive the same content and the codings in which it is available. SME matches these to the user terminal capabilities and sends to NME. The grouping considers current load, available capacity, QoS capabilities of the RATs within users’ reach as well as rules set by NUM. Next, we focus on the session setup procedure, which illustrates the messages exchanged during session initiation that are relevant to Network Management (both NME and NUM).
Network Role in Context-Aware Group Setup

The Session Management, once the matching of content availabilities and users’ content capabilities is performed, sends the list of users and their supported content codings to the NME. This starts the sub-grouping process in the NME that is composed of three steps.

Firstly, NME triggers NUM to select for each user the interface (i.e., the RAT) that will be supported and the content coding that will receive. Upon this trigger, NUM acquires from the Context Management system the current networking and environment context of the users as well as the current network context. Based on this context, NUM forms different “possible” transmission arrangements (i.e., different combinations of groups of users that will be served using a specific RAT and receive a specific content coding) that can be used for the multicast content provision and the capacity requirement of each transmission arrangement is estimated. Then, based on some rules that the transmission arrangement must obey during the content provision within the network, the “acceptable” transmission arrangements are identified and the one with the least amount of capacity requirements is selected and adopted. “Possible” transmission arrangements are those that can provide the content to the users with the required QoS. On the other hand, “acceptable” transmission arrangements are a subset of the “possible” transmission arrangements that conform to the rules that should be obeyed during the content provision within the network. These rules are defined dynamically by the NUM by using some intelligence and by considering both the current and the history context information of the network and users collected through time. For example, previously received context is compared with current context for similar patterns to be located. Based on the similar patterns located, using some intelligence, NUM detect trends and forecasts of undesirable events are possible to occur in a short time (e.g., congestion in the Network, overloading of certain RATs, users’ QoS degradation, etc.) and sets some rules that the transmission arrangement must obey in order for these events to be avoided. Once the transmission arrangement to be adopted is selected, NUM triggers each Terminal for an interface and IP address update. Once the new IP addresses of the Terminals are received, NUM informs NME about its decision.

Secondly, NME decides on the multicast groups based on the user’s and operator’s context, and it chooses the optimal way to group the users based on optimization policies that can maximize the QoE of the user.

Lastly, NME will send this result and updated interfaces to NUM and check for available paths between the source and users that respect the QoS constraints and optimize the resource allocation. This process is partially cyclic and may require some sub-iterations or adaptations of a decision previously taken. Still it allows the separation and simplification of processes towards the autonomy of the system. Afterwards, each of the multicast subgroups will trigger the resource reservation and multicast routing. In the end NME pushes the Session Management (SME and SUM) to invite all the users to the multicast groups and the content provider to start streaming. The process is depicted in Figure 4.

Network Role in Context-Aware Group Modification

The group modification capabilities and thus the system adaptability is one of the major strengths of this architecture since it is able to rapidly adapt to various environment changes and maintain the user experience. In fact, the architecture must firstly be able to quickly detect any changes, to evaluate the impact on the ongoing sessions and be prepared to enforce modifications on the subgroup possibly switching the streams some of the users are receiving. Three major triggering possibilities were considered: updates of the group members, modifications on network elements which may influence the experienced QoS, and changes due to user’s mobility.

A first one is related with Group Session Modification, usually resulting from a change
in the user context implying that a different content is received by the user. This represents the ability of users to join or leave the group session. This is initiated at higher levels in the group manager and content selector and passed to the SME that propagates it to the Network Management and other modules in a way, very similar to session initiation. The removal of users can reduce size or even terminate an existing sub-group. Plus, addition of users has to take into consideration that the stream is already progressing and the content will only be viewed from that point forward. This is only considered when the new user viewing experience is not compromised, since no user wants to be watching a TV show and suddenly jump 3 or 5 minutes in time.

The second type is related with the Sub-Group Modification, which only affects the actual QoS of a set of users and allows them to be switched between sub-groups. This actually incorporates two triggering possibilities, one related with the network nodes and the paths between them, some network issue may modify the QoS weights on each network track, and another related with the user mobility and its re-attachment on a different service. This way, the actual session group is preserved and

Figure 4. Network Management related messages in session initiation (adapted from Antoniou et al., 2009)
only the concerned sub-groups are updated. Whenever this happens, some users get “promoted” (or “demoted”) to a group with different quality of service. This can be triggered by the implemented IPT traffic resilience mechanisms, where the network conditions are significantly altered: a link or a router may go offline or back online, the QoS conditions may be altered, the access network may become overloaded, or the terminal may be forced to move into a different network with different conditions.

Eventually, session mobility between terminals with different characteristics and updates of operator policies will also trigger sub-group modifications. The process is depicted in Figure 5.

**PROTAGATING CONTEXT TO CONTENT**

In the previous sections we presented how context-awareness was enabled at the session and network levels, describing the proceedings on how sub-groups are formed, the usage of context information in this process and further describing mechanisms activated in order to assure QoS across the whole transport and network layers. In this section we describe the mechanisms involved in delivering the correct media types to the right users and explain the importance of this process in the overall value chain of the content to context management and distribution.
Motivation: Same User, Different Media Types, Different Sub-groups

Although the sub-grouping is mainly done in the Network Management functional entity, the Session Manager is the entity responsible for managing the content-to-user and user-to-content relationships. Therefore, based on the sub-grouping information provided from the Network Manager, the Session Manager must initiate SIP sessions towards the end users as well as the CtPD entity (Media Delivery Function). Despite the complexity of this process, by using SIP, the session establishment, renegotiation, termination and mobility becomes quite straightforward.

Although all users will be receiving the same content, the media types may vary according to their preferences, needs or current conditions, allowing each user to receive its own personalized stream. Moreover, note that a subset of the users might belong to the same sub-group concerning one media type and different sub-groups in others (example depicted in Figure 6).

After identifying the required sub-groups for a specific content (group with similar context) the Session Management entity initiates the session establishment process with the CtPD. Figure 7 shows an example of the SIP INVITE message for a specific audio sub-group (audio capabilities).

On the other hand, Figure 8 shows a sequence flow from the messages between the Session Management entity and the CtPD concerning all sub-groups session initiation and corresponding session establishment. Simultaneously, Session Management triggers the session initiation towards the end user. Figure 9 exemplifies the message that is sent to user x.

When this message reaches the user terminal, according to the network capabilities, the behavior may vary. If the terminal/network is multicast capable, the device will send a JOIN message towards the multicast addresses included in the initial INVITE message. If the device only supports unicast connections, it will answer the request with a 200 OK message containing the ports it will be expecting media from. Consequently the Session Management entity will forward this information towards the Network Management entity, which will have the responsibility of updating the overlay leaf node with this information.

After the session is established towards the end user, Session Management activates the CtPD delivery process, which consists in creating unicast sessions with the overlay source nodes on the overlay trees. This step activates the media transmission across the entire multicast overlay trees. Consequently, the media flows are established, finalizing the process of context to content propagation.

The Importance of Sub-Grouping

The importance of personalization in multiparty multimedia services strongly motivates content providers, operators and other players to adapt the user experience of these services. Often, adaptation raises scalability and performance concerns, which need to be addressed efficiently. Creating different sub-groups for different media types, allows users to receive the multimedia content that is most suitable to them,
not only according to their personal, device and environmental contexts but also considering the current network context information. This compromise allows both users and operators to achieve an optimal point in what concerns personalization vs. scalability. Furthermore, this will boost the user perceived QoE as the sub-grouping mechanisms allow personalization, contextualization and adaptation of content/services, facilitating further interactivity and mobility tasks. By simultaneously allowing, the operators to optimize and save network resources, services become cheaper and consequently more attractive to the end user.

EVALUATING CONTEXT-AWARE MULTIPARTY SESSIONS

Testbed Details

After describing the architecture, it is important to understand how system components can be tested against initial requirements. Considering the amount of developed components, the

Figure 7. SDP information from INVITE message towards CtPD (adapted from Antoniou et al., 2009)

Figure 8. Sequence Flow between Session Management and CtPD (adapted from Antoniou et al., 2009)
complexity of the network elements, and the different configurations required for the tests, the environment was setup using virtual machines (VMware ESXi Hypervisor).

Although the overall C-CAST architecture (PT Inovacao, n.d.) involves several components, we only focus on the entities responsible for the session and network layers used to support autonomous context-aware multiparty communications in heterogeneous mobile systems. For this testbed we used a number of virtual machines, with Ubuntu Linux. The characteristics and other implementation details of these can be found in Table 1.

It is important to understand how the different components communicate between themselves. Table 2 presents the different interfaces and respective technologies used in these communications. Furthermore, Figure 1 depicts the network topology of the testbed.

### System and Components Evaluation

In order to evaluate the proposed solution, it is important to validate all the pre-defined functional requisites described in C-Cast (PT Inovacao, n.d.). Moreover, it is necessary to evaluate the following non-functional requisites:

- **Performance**: response times between components, CPU, memory for both the algorithms used and the interface communication between modules.
- **Reaction time to context changes**: the time it takes for context to content adaptation.
- **Scalability**: how the system usage can scale, (how many simultaneous users, groups and multimedia sessions can be achieved in a scenario).
- **Flexibility**: how easily can the architecture adapt to different context types and how generic are the interfaces so that the modules and algorithms can be replaced, extended or improved.

### Personalization vs. Efficiency

The impact personalization has on the overall efficiency of the multimedia delivery

**Economical Issues**: correlating the previous points with real-life scenarios, what would be the economical impact of such innovation (e.g., optimized, self-adapted and real-time network dimensioning). Could operators save or gain more money from it?

**Quality of Experience**: whether the user’s perceived experience improves with the introduction of such solution and if the system
performs the same or better that current system in problematic situations.

At this point in time, only the functional tests have been performed, and it was possible to verify that the communications between the identified entities were correctly performed.

Nevertheless, all the previously mentioned requisites will be tested in the following way:

- See how CPU, memory and response times vary according to the number of users, types of context or multimedia content

Table 1. Virtual machines, components and technologies description

<table>
<thead>
<tr>
<th>PHy ID</th>
<th>VM Name</th>
<th>System Properties (CPU, Memory, HD, Network)</th>
<th>Components running</th>
<th>PHy ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC2</td>
<td>Anne</td>
<td>2 VCores / 2GB RAM / 30GB HD / 4 shared GigaEth</td>
<td>IPTnode, MTO node (Source Overlay Node)</td>
<td>C/C++, Diameter, mRouted</td>
</tr>
<tr>
<td>PC2</td>
<td>Betty</td>
<td>2 VCores / 2GB RAM / 30GB HD / 4 shared GigaEth</td>
<td>IPTnode</td>
<td>C/C++, Diameter, mRouted</td>
</tr>
<tr>
<td>PC2</td>
<td>Claire</td>
<td>2 VCores / 2GB RAM / 30GB HD / 4 shared GigaEth</td>
<td>IPTnode, MTO node (Leaf Overlay Node)</td>
<td>C/C++, Diameter, mRouted</td>
</tr>
<tr>
<td>PC2</td>
<td>Dianne</td>
<td>2 VCores / 2GB RAM / 30GB HD / 4 shared GigaEth</td>
<td>IPTnode, MTO node (Leaf Overlay Node)</td>
<td>C/C++, Diameter, mRouted</td>
</tr>
<tr>
<td>PC2</td>
<td>Elaine</td>
<td>2 VCores / 2GB RAM / 30GB HD / 4 shared GigaEth</td>
<td>IPTnode, MTO node (Leaf Overlay Node)</td>
<td>C/C++, Diameter, mRouted</td>
</tr>
<tr>
<td>PC1</td>
<td>NM</td>
<td>2 VCores / 1GB RAM / 20GB HD / 1 shared GigaEth</td>
<td>NME, NUM, IPT, MTO ctrl, NIS</td>
<td>C++, Gsoap,</td>
</tr>
<tr>
<td>PC1</td>
<td>SM</td>
<td>2 VCores / 1GB RAM / 20GB HD / 1 shared GigaEth</td>
<td>SME, SUM</td>
<td>Java SDK 6, Sailfin 2.0</td>
</tr>
<tr>
<td>Mobile Phone</td>
<td>G1</td>
<td>Media player, mobile</td>
<td></td>
<td>Java</td>
</tr>
<tr>
<td>Wireless AP</td>
<td>WRouter</td>
<td></td>
<td></td>
<td>C/C++</td>
</tr>
</tbody>
</table>

Table 2. Technologies involved in the interfaces between different entities

<table>
<thead>
<tr>
<th>Components</th>
<th>Description of Interface</th>
<th>Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM - CtPD</td>
<td>Request content info</td>
<td>HTTP Rest Interface</td>
</tr>
<tr>
<td>SM - CxB</td>
<td>User context acquisition and subscription</td>
<td>HTTP Rest Interface</td>
</tr>
<tr>
<td>SM - NM</td>
<td>Resource reservation and sub-group management</td>
<td>Web Service</td>
</tr>
<tr>
<td>SM - CtPD</td>
<td>Signaling management of multimedia communications</td>
<td>Session Initiation Protocol (SIP)</td>
</tr>
<tr>
<td>SM - Client</td>
<td>Signaling management of multimedia communications</td>
<td>Session Initiation Protocol (SIP)</td>
</tr>
<tr>
<td>NM - CxB</td>
<td>User context acquisition and subscription</td>
<td>HTTP Rest Interface</td>
</tr>
</tbody>
</table>
involved (Tigris.org, 2008; JUnit, n.d.; Source Forge, 2010).

• By using different context triggers, evaluate minimum, maximum and average response times.
• Vary number of users involved in the tests to allow understanding of how good the system can scale.
• Identify the balance point between what users and operators want, need and desire.
• Verify how much bandwidth can be spared, how many new Quality of Service (QoS) classes can be introduced and evaluate how this offer can be translated into new and differentiated business offers within the operators client base.
• Make surveys to understand what users want, desire and need and compare with what our solution offers. If possible, use a small set of users to test our testbed and prototype implementations.

CONCLUSIONS AND FUTURE WORK

In this paper we present an innovative way to achieve self-optimization through context-awareness in multiparty converged mobile systems. This is achieved through the dynamic re-definition of service groups (sub-grouping) in a converged architecture.

A general overview of the sub-grouping process was given with reference to the system architecture, to place the proposed innovation within a system scope. Subsequently, the focus shifted to particular aspects of the sub-grouping process and the use of the reference architecture in this process; in particular, we have shown how the process begins at the session level, is refined at the network level, and is finally propagated at the service level to the content. As a result, the content received by each defined sub-group has been adapted to the users’ preferences, situations and contexts on the one hand, and on their network capabilities on the other hand, improving both network resource usage and user experience.

Future work aims to implement this architecture in a testbed setup in order to test specific scenarios that can be supported, in order to demonstrate the network and session enhancements. More specifically, the elements required to perform and enforce sub-grouping both at the session and network level will be implemented: context providers, session and network management, multiparty transport overlay and IP Transport. Relevant performance measures will be collected and specific sub-modules...
participating in this self-optimization process will be individually enhanced and evaluated.

ACKNOWLEDGMENT

This work is funded by EU ICT C-CAST (Context Casting) project.

REFERENCES


ENDNOTE

1 The dynamic over-provisioning mechanism of IPT ensures that IP routing path candidates are QoS-capable. Also, NUM and IPT collaborate to ensure QoS preservation on branches of the MTO despite context change.

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