Mobile Plug-and-Play Architecture for Collaborative Hybrid Peer-to-Peer Applications

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***Abstract*— Increasing heterogeneity of networks, services and applications emphasizes the need for middleware as an essential part of the information technology infrastructure. To implement novel 3G and beyond 3G mobile applications and services, the light-weight middleware utilizing application supernetworking- and hybrid peer-to-peer (P2P) – client/server concepts can be considered. Application supernetworking means collaboration of applications that utilize a set of common functionalities for sharing contextual information and managing sessions and connectivities. Hybrid P2P – client/server concept aims to optimize the network system features by exploiting the advantages of both the P2P and client/server domains. Hybrid scenarios could include e.g. utilizing secure client/server –based authentication for P2P networks. We have developed a Plug-and-Play Application Platform (PnPAP) mobile middleware to support novel application development and improved user experience. PnPAP provides support for seamless usage of multiple simultaneous applications, protocols and network connectivities. Required user interaction is reduced and new collaborative application scenarios, utilizing both P2P-client/server networks, are enabled. For the application developers, PnPAP enables faster development cycle by providing a unified API definition for protocol, session and connectivity management. Functionalities of the PnPAP core are controlled with state-machines, where the rules of operation can be dynamically updated over-the-air by the service provider. This enables managing the heterogeneity in a more flexible way than in the traditional systems. given in this document.**

Middleware, application collaboration, mobile peer-to-peer, application supernetworking, context and location awareness

I. INTRODUCTION

All-IP communication means that practically all network traffic on the end-to-end communication path is carried over the Internet Protocol (IP). It also enables using heterogeneous access networks with a unified service platform such as the IP Multimedia Subsystem (IMS) [1]. Defined in the Third Generation Partnership Program (3GPP), the IMS system plays an important role in promoting global fixed-mobile convergence and service roaming. It provides authentication and billing functionalities for building new operator-friendly mobile services over a rich, convergent All-IP communication environment. While All-IP concept has strong market pull due to the popularity of IP based Internet applications, IMS is the technology needed to push their implementations to the operator network environment.

Efficient implementation of All-IP applications and services can benefit from local (in device) optimization through middleware solutions. The importance of middleware solutions will continue to grow as long as computing and communication systems remain heterogeneous [2]. Middleware is the essential element that combines session and connectivity management into one unified platform that can be accessed through a well-defined Application Programming Interface (API). Application developers can utilize this interface to implement novel peer-to-peer and group communication applications into the operator network.

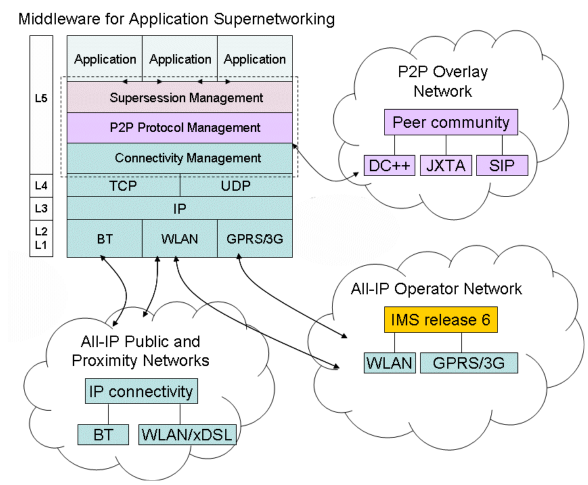

Figure 1. Application supernetworking and communication middleware.

Application supernetworking enables seamless collaboration of multiple simultaneous group based applications. For instance, a supernetworked navigation application can introduce *supersession* capability, which means that new application sessions such as file sharing can be initiated from the parent session. As illustrated in Fig. 1, application interactions can benefit from middleware support for optimized access to the heterogeneous All-IP (TCP/IP) networks and IMS service platform. Middleware can also provide local optimization to achieve the "always best connected" paradigm.

The Applications Creation, Networking and Service Management (Application Supernetworking/All-IP) project was financed by TEKES Technology Agency of Finland), Nokia, Elektrobit, TeliaSonera Finland, Serv-It, and IBM.

978-0-7695-3313-1/08 $25.00 © 2008 IEEE
DOI 10.1109/SERVICES-2.2008.30

II. TECHNOLOGY DRIVERS FOR APPLICATION SUPERNETWORKING

An evolutionary step from one-to-one communication services such as Short Message Service (SMS) and Multimedia Messaging Service (MMS) is the one-to-many communication paradigm. One-to-many communication refers to group interaction with distribution of both commercial and user-created, feature-rich content. This can be implemented either with a traditional client-server solution, or in a peer-to-peer (P2P) fashion, or using hybrid architecture. P2P challenges the client-server architecture both as the main communication paradigm and as the de facto solution for distributing content.

Currently, P2P applications are located at the edge of the Internet, using the operator networks merely as byte pipes. Clearly, this is not the optimal situation for operator business. Implementing one-to-many services to the operator network domain will have twofold benefits: on one hand, they will act as a market counter-force for the edge applications that are disrupting operator business. On the other hand, these novel services will create new business potential and value for operators' IP based service platform investments such as IMS.

A. All-IP, SIP and IMS

The All-IP concept is essentially developed around Universal Mobile Telecommunications System (UMTS) and 3GPP standardization efforts, more specifically 3GPP R4 (Release 4) and upwards. UMTS R4 has introduced IP transport in the circuit-switched core network so that voice traffic can be carried in IP packets. Later R5 introduced IMS as a new service platform for implementing IP based call control and multimedia signaling using the Session Initiation Protocol (SIP), developed by the Internet Engineering Task Force (IETF). The IMS service model has been adopted also by 3GPP2 and ETSI TISPAN. Current R6 provides integrated operation with Wireless LAN networks and adds Multimedia Broadcast Multicast Service (MBMS), High-Speed Uplink Packet Access (HSUPA), and enhancements to IMS, such as Push-to-Talk over Cellular (PoC) and Unlicensed Mobile Access (UMA).

The Open Mobile Alliance (OMA) focuses on facilitating multi-vendor interoperability for mobile service enablers such as Digital Rights Management (DRM), PoC, client provisioning, device management, games services and multimedia messaging. The OMA architecture charter ensures that IMS capabilities are consistently used in order to prevent fragmentation of standards and maximize the reuse of 3GPP and 3GPP2 IMS capabilities. Protection against illegal distribution and usage of IPR protected content in one-to-many communications relies on using OMA DRM specifications. As these essential standardization organizations and their industrial member companies have provided this level of technology push, it is clear that IMS can be considered as one of the key technology drivers for implementing new operator centric services.

SIP is the key signaling protocol for the IP based services in 3G networks, providing basic functionalities for multimedia session management, signaling and addressing. IETF has a working group, specialized in defining extendable features for presence and instant messaging, called SIP for Instant Messaging and Presence Leveraging Extensions (SIMPLE). The extensions to XML based Presence Information Data Format (PIDF) profile, defined by SIMPLE, can be used for delivering context information between communicating nodes. For instance, Location Object PIDF-extension (PIDF-LO), defined in Geographic Location/Privacy (GEOPRIV) working group, can be used for delivering location information.

IETF has recently formed a P2PSIP working group for adapting P2P with features suitable for SIP [3][4]. As the P2PSIP charter defines, the goal of P2PSIP WG is to allow the use of SIP in a distributed manner, where the establishing and managing of sessions is principally handled by a collection of decentralized peers, rather than centralized servers as in the basic client/server SIP. The concept behind P2PSIP is to leverage the distributed and failure-tolerant nature of P2P by building a structured overlay network of peers to provide services for a network of SIP clients, without changing the client structure too much. This removes the need for centralized server components and allows true P2P networking between the SIP nodes. The focus of P2PSIP is constrained to the node and resource location and the essential supportive functions, such as overlay management, query routing, bootstrapping, registration, Network Address Translation (NAT) and Firewall traversal, authentication and security. The goal has later extended towards a more general P2P architecture, where the applications can also directly utilize P2PSIP, instead of limiting the usage to only SIP-based communication.

IMS provides tools and trusted infrastructure for network application development. When the required IMS servers are available in the visited network and the user's home network, information about the user and the services can be reliably communicated to ensure the smooth setup of application sessions. Signaling between end-user terminals in IMS is carried through the operator-controlled servers. To hide underlying network details, IMS servers may modify SIP headers seen by the terminals. Among other things, IMS features the identification of the mobile user, binding the user's identity used in services to the identity that is known to the mobile operator. This enables online and offline charging of services so that the payment is added to the user's prepaid or postpaid mobile phone account's invoice. IMS also enables security measures in which the user is identified based on a challenge-response scheme, which can be implemented using IMS Authentication and Key Agreement (AKA) with a User Services Identity Module (USIM) card, or HTTP digest based authentication. IPSec Encapsulating Security Payload can be used to encrypt SIP traffic between nodes. Data encryption is especially useful in inter-domain network traffic, i.e., on the packets' way from operator A to operator B. Different access networks in a converging All-IP world introduce additional complexity to IMS signaling since not all access networks are integrated with IMS; for access independence, ETSI TISPAN has created the IMS-based Next Generation Network (NGN). [5]

Despite IP networks not being inherently Quality of Service (QoS) friendly, IMS provides tools for negotiating and setting up the desired QoS. Mobile terminals negotiate QoS parameters with special SIP INVITE requests that contain QoS-aware Session Description Protocol (SDP) messages. However, the terminal-to-terminal message sequence for QoS-enabled session setup is relatively complex and lengthy. IMS supports also supplementary services such as presence authorization lists and user group management; the XML Configuration Access Protocol (XCAP) is used for configuring these services on the dedicated application servers. [5]

B. Emerging Hybrid P2P - Client/Server Systems

Before introducing the idea behind hybrid P2P and client/server systems, the confusion around the definition of P2P communications needs to be removed. First, low layer P2P means ad hoc type of wireless communications that enables handsets to communicate directly with each other without base stations [6]. Second, upper layer P2P means overlay architecture that may utilize whatever lower layer communication architecture, whether it is fixed or mobile, or infrastructure or ad hoc type. Upper (i.e. application and service) level P2P is more versatile for implementing novel group based multimedia applications as it can reach more extensive service coverage through higher levels of abstraction. For example, the upper layer overlay architecture can utilize heterogeneous lower layer fixed and wireless communication channels in a holistic manner. In the rest of this paper, the term P2P refers to upper layer P2P.

The importance of interoperability between the P2P and traditional client/server domains will be emphasized in the future. The P2P and client/server networks are very different in their nature. On this account, the services developed in these architectures differ in their purpose of usage and their targeted user segment. P2P services normally exploit the scalability of the underlying networks, and utilize resources of the users' devices to achieve low administration effort, whereas client/server solutions utilize the better controllability, performance and security of the centralized services. Typical P2P services are extemporaneous, free services for leisure time use, whereas the commercial services are more often placed on servers and thus more permanent. The main advantage of P2P in commercial use is its easy and cheap deployability, especially with the services that require a lot of storage space, such as video sharing services. Thus, service providers can utilize P2P for providing low-cost services that would be unprofitable if the content was stored in their own centralized servers.

Hybrid P2P - Client/Server systems aim to optimize their costs and features by exploiting the advantages of both the P2P and client/server domains and networks. One example scenario of hybrid system is presented in [7]. It utilizes IMS as a managed, operator-mediated service provisioning system for P2P networks. Hybrid approach seems especially interesting with IMS and P2PSIP networks, as they both provide a SIP interface for applications and are compatible in this sense. This type of collaboration can be enabled with advanced gateway solutions, leveraging both novel IMS services and legitimate P2P services in the operator network domain.

C. Towards Mobile P2P Systems

Recent advances in wireless communications have introduced higher capacity and better end-to-end quality of service (QoS) for various mobile networks. Naturally, when P2P and other bandwidth-intensive applications can utilize higher communication bitrates for mobile multimedia (e.g. UMTS instead of GPRS), the users perceive higher communication quality [8]. In addition, new mobile devices enable richer multimedia presentation and usage. As a result, mobile users can use similar type of services as in the PC environment.

P2P as a phenomenon, however, raises concerns about security and IPR violations. DRM technologies might provide some solutions to these problems. When combined with user authentication (USIM) features provided by the IMS service platform, we see that introduction of legitimate P2P brings an interesting venue for new multimedia communication services.

One of the main obstructive forces in the introduction of mobile P2P services has also been the lack of profitable business models. However, with carefully considered pricing, the usage of mobile P2P can be more profitable for content providers and mobile operators than the traditional centralized mode of delivery [9]. Combining mobile P2P services with centralized client/server elements, such as IMS, also emphasizes deploying profitable mobile P2P solutions. In addition, thanks to flat-rate pricing, the usage models of mobile handsets and PC computers are converging.

If measured in data traffic volume, P2P applications and services are dominating the home networking domain and fixed-line Internet communications, driving fixed broadband access usage. [7] European level study of more than 500 active subscribers showed that also mobile P2P is increasing its volume. For instance, mobile P2P program Symella generates 3% of the total traffic, clearly bypassing the traffic statistics of e.g. mobile RealPlayer [10].

D. Middleware Solutions

To introduce better usability of simultaneous mobile applications (in local device and between remote devices), middleware solutions are needed to support new type of dynamic plug-and-play interactions. Currently, the mobile users need to initiate several applications to achieve advanced communication purposes. The required user interaction and configuration is hindering the usability of new mobile services.

Middleware architectures are important technology enablers for optimized communications and services. They provide local and end-to-end level optimizations and tailoring of functionalities and parameters with existing resources and interfaces. For example, the ReMMoC middleware [11] provides support for using multiple protocols to accomplish greater interoperability. However, it neither provides P2P functionality or connectivity management nor e.g. middleware adaptiveness based on context information.

Communication architecture for spontaneous systems [12], based on the Open Service Gateway initiative (OSGi) framework, enables downloading user interface bundles in a plug-and-play manner. It uses Java virtual machines as the execution platform, and P2P architecture as the communication platform. With this approach the network appliances do not need to support full protocol stack implementation. SIP is used to negotiate different types of sessions. However, collaboration of applications is not as flexible as in our model.

Service Oriented Architecture (SOA) paradigm is one of the recent advances in the middleware solutions that has mainly focused on enterprise servers, but has also been tested on mobile P2P [13]. Our approach is similar to SOA and other generic middleware solutions in providing abstraction to application developers and flexibly combining new service components. However, our middleware can take into consideration various e.g., context-aware parameters even in a more flexible manner than in an SOA web-service based model.

III. PLUG-AND-PLAY APPLICATION PLATFORM

We have developed a middleware called Plug-and-Play Application Platform (PnPAP) [14] that provides a platform for supernetworked mobile applications and allows them to flexibly interface with various protocols and network connectivities. Protocols can include e.g. SIP, DC++, JXTA and P2PSIP, and the network connectivities e.g. GPRS, UMTS, WiMAX, Zigbee, Bluetooth, and WLAN. As PnPAP provides an access concurrently to SIP and several P2P protocols, the applications above PnPAP can easily utilize the hybrid P2P - client/server scenarios described in section IIb. Users are able to reach each other with supernetworked applications e.g., by selecting other users from navigation application map interface to initiate new application sessions for e.g. file sharing, messaging or real-time communications. With these design choices, our approach helps making the application development life-cycle shorter and provides new tools for service providers to tailor their services.

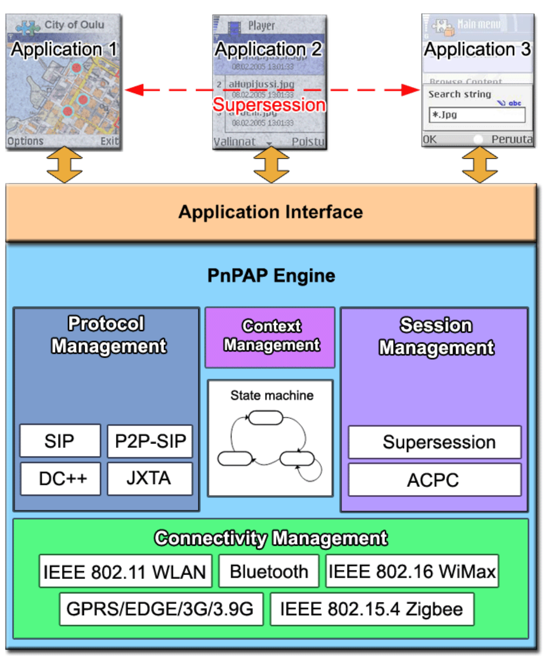

Figure 2. Plug-and-play Application Platform middleware functional domain presentation.

As illustrated in Figure 2. , PnPAP middleware resides between application and transport layers in the protocol stack level of presentation. Functional domain presentation in Figure 2. shows how protocol, session, connectivity and context management are contained within the PnPAP. The protocols and connectivities are controlled holistically, meaning that PnPAP selects the combination of protocols and connectivities that fits best the requirements of the situation.

A. *Dynamic State Machine Control*

At the heart of the PnPAP decision-making process are dynamically reloadable state machines that control the system behavior. Our solution utilizes SteMach architecture [15] that consists of two main components: State Machine Executor (SME) and communication component. The SME executes state machines that, for instance, manage connectivity based on the user's context. The communication component manages communication between the SME and the rest of the PnPAP engine. Events sent by the engine trigger state transitions; actions are executed when states are exited, transitions are taken, or new states are entered. Some actions generate events that are sent to the PnPAP and trigger e.g. the physical connectivity to be changed. The SteMach architecture uses machine-interpretable state machine descriptions. The language used in describing the machines is Resource Description Framework (RDF), which is serialized to either Extensible Markup Language (XML) or Notation3. This approach allows state machines to be handled as data: they can be modified without changing the PnPAP code and new state machines can be downloaded and started on the fly.

B. *PnPAP Intercommunication*

For optimized performance and compatibility with multiple networks, PnPAP nodes need to interact with each other. We call the developed interaction mechanism of PnPAP nodes as PnPAP Intercommunication Architecture. It enables the exchange of protocols, connectivity parameters and -control messages, supersession control messages, as well as status and context information of PnPAP nodes.

One of the main benefits of the PnPAP architecture is the independence of any centralized control. On this account, it is important that the PnPAP intercommunication architecture, as well, incorporates as few centralized components as possible. In the current prototype, we have utilized the basic SIP MESSAGE method for implementing the needed intercommunication messaging. For finding the specific PnPAP nodes and their resources, PnPAP can use the existing installed protocols implementing the resource exchange, such as JXTA.

For implementing these functionalities in future, we propose utilizing the forthcoming P2PSIP protocol [3] as the default protocol. Using SIP enables many hybrid P2P–client/server scenarios. An example scenario is to utilize the IMS platform for implementing operator related features such as billing and authentication when PnPAP nodes are located in a loosely controlled P2PSIP network.

C. Protocol- and Connectivity Management

PnPAP controls the use of communication entities, i.e. protocols and connectivities, using cross-layer approach, in which the information and control of the different OSI layers are shared for improving and optimizing the performance, quality of service and other desired characteristics. The combination of protocols and connectivities in use is kept optimal by letting the user or the applications set the parameters used for deciding the protocol-connectivity combination. The relative goodness of interchangeable entities is then determined by protocol and connectivity policy and the evaluation algorithm [16].

The policy is implemented as state machine rules including policy representation and weighting of selected criteria. Evaluation algorithm takes various parameters such as communication channel information, context information and application settings as an input. When e.g. Bluetooth or WLAN availability is recognized, an event is generated. This event is sent to the state machine that then decides whether to trigger a change of protocols or connectivities.

Decision making utilizes any selected calculation algorithm to determine the best protocol-connectivity pair for a given situation. If e.g. an application requests functionality that none of the current protocols provide, PnPAP can search a suitable protocol from another PnPAP node through PnPAP intercommunication. In connectivity level, numerous connectivity parameters, such as Received Signal Strength (RSS), can indicate movement out of the cell range, triggering imminent handoff to another overlaying network (e.g., falling back from WLAN to GPRS). Holisticity refers to the ability to couple the connectivity policy management with rich contextual data such as location or application usage situation.

D. Context Information

PnPAP middleware shares context information with other PnPAP nodes to optimize its behavior. Context information is divided into two categories. Application specific context information may contain items such as location, presence, heart rate, altitude, speed and temperature. PnPAP specific context information, in turn, contains items related to supported protocols, available connectivities, and supported types of user-level interaction, i.e., the supernetworked applications installed on a given mobile node. PIDF-LO is used for expressing location attributes.

Our work also includes considerations on positioning technology: GPS or cell positioning outdoors, WLAN positioning indoors, for example. PnPAP can be tailored to make such handovers transparent to the mobile user, who can thus have in hand all the available positioning technologies with different geolocation accuracy resolutions in a unified manner. The modularly designed PnPAP can be easily extended to support new technologies that, for example, provide new type of sensor data. This illustrates the notion of holisticity, how to utilize the optimal set of protocols and parameters for the given application or service scenario.

E. Content Push and Superdistribution

For flexible service life cycle management, we have designed and implemented Agile Content Push Control (ACPC) within PnPAP [3]. ACPC enables on-the-fly application installation and licensing, a kind of content push, when user A requests an application session with user B who might not have the required application yet. ACPC aims to enhance the distribution of mobile content, such as game applications and media files, within a peer group community. The IMS can be applied in ACPC for guaranteeing the pusher's identity and providing a reliable payment channel in an IP-based environment. A licensing service could be built on top of the IMS Application Server architecture. Furthermore, as ACPC is used for session-oriented multi-user applications, session signaling can use the network's existing IMS facilities.

IV. Prototype Implementation

Our prototype of PnPAP is implemented on the Symbian based Nokia Series 60 operating system. Through real-life user scenarios, we have developed proof-of-concept mobile applications to demonstrate the feasibility of our approach. Our results show that the application development cycle can be reduced and the usability of simultaneous applications can be improved [17].

A. Mobile File Sharing Application

Mobile File Sharing Application (MFSA) is a mobile version of a typical P2P file sharing application. It provides basic functionalities such as sharing, searching and downloading content. Additionally, peer group management and instant messaging functionalities are provided, the first, however, requiring support from the underlying P2P protocol. MFSA itself includes only a user interface and an engine maintaining state information and communication interface to PnPAP. It uses PnPAP for executing network related functions (e.g. search, share, download, etc.) and file system access.

In a more advanced version, DRM functionalities could be implemented according to the OMA 2.0 DRM standard, and user authentication could utilize the IP Multimedia Services Identity Module (ISIM) feature of IMS [1].

B. Navigation Application

NaviP2P is a navigation application that provides GPS-based navigation enriched with peer group and supersession functions. The selected peer group members are located on a map with the appropriate context information such as names, location, available connections and presence. Maps are downloaded from a public HTTP server. The delivery of context information between peer group members' applications is managed with PnPAP intercommunication using SIP MESSAGE extensions.

In a supersession start-up, a session with a remote user can be extended with other applications (file sharing, instant messaging, etc.) that may be started directly from the map view. As illustrated in Fig. 3, after selecting a peer, different types of interaction are listed for the user to choose from. PnPAP takes care of listing the possible types of interaction and starting sessions with the correct parameters. Fig. 3 illustrates a supersession taking place between NaviP2P and Wellness Application. Thanks to supersessions, NaviP2P can be also considered as a graphical user interface for different activities within peer groups.

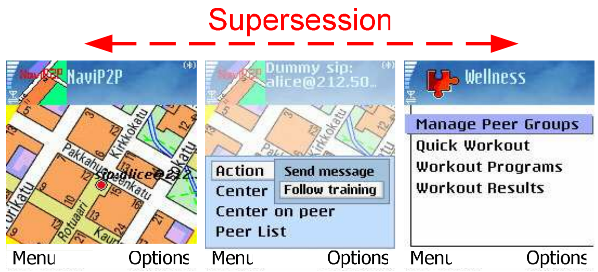

Figure 3. Supersession between NaviP2P and Wellness Applications.

C. *Wellness Application*

Wellness Application is a tool for sport and leisure groups who want to share their context information related to their physical exercising. The group members can plan and monitor their own or, if permitted, other group members' exercises. The exercise data is automatically stored for later analyzing or creating an exercise diary [18].

The exercise data can be exchanged among group members in near real-time by using SIP-based PnPAP intercommunication. The shared exercise data can be accessed also with MFSA. If the accessing node does not have the same P2P protocol available, it can be easily retrieved and taken into use in a plug-and-play manner by PnPAP. Wellness Application currently uses two kinds of context information: location information from a GPS device and heart-rate information from the sports computer. In the future, location information could also be received from other positioning sources such as Bluetooth, WLAN, or cell ID, to facilitate also positioning technology handover.

D. *Results of Usability and Performance Evaluation*

To evaluate the feasibility of our plug-and-play architecture and especially the application supernetworking concept, we measured the differences in the needed user input and the mobile handset run-time Random Access Memory (RAM) consumption [17]. When measuring the required user interaction, the test case was to start the MFSA and access a group member's list of files. The measured variables were the number of needed user actions and the average time used in completing the task. The phone used in our tests was the Nokia 6680 with PnPAP, MFSA and NaviP2P installed. The measurement results in Table I and Fig. 4 illustrate the improved usability and performance.

TABLE I. COMPARISON OF REQUIRED USER INTERACTION

	Traditional	Super-networking	Ratio	Improvement factor
User input, min #	11	3	27%	2,67
User input, max #	30	13	43%	2,31
Session initiation time, min (s)	26	10	38%	2,60
Average			36%	2,53

Measurement results demonstrate that the application supernetworking scenario reduces both the needed user interaction and memory consumption when more than two collaborative applications are running simultaneously. The amount of user interaction has a significant influence to the experienced usability. In average, the user can perform the same functionalities with less than half of the interaction in comparison to the traditional interaction model.

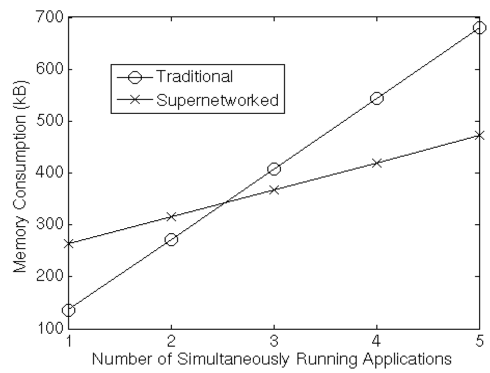

Figure 4. Comparison of memory consumption.

The memory consumption of the supersession case goes below the traditional case already when there are three simultaneously running applications. Thus, application supernetworking can help to save memory in the mobile devices. When combined with tailored connectivity management, the benefits of the supernetworking concept are evident for the rich communication scenarios of the future.

V. CONCLUSIONS

Group communication and service management aspects can be leveraged through advanced hybrid P2P, plug-and-play and seamless connectivity paradigms. In this paper, we have provided a survey of technology drivers for new type of application interaction and introduced a mobile middleware called Plug-and-Play Application Platform (PnPAP). PnPAP implements session management for supernetworked applications, and enables connecting users to multiple communities over heterogeneous distributed and centralized networks. It facilitates improved user experience by optimizing seamless usage of multiple simultaneous applications, protocols and network connectivities. We call this application supernetworking, which is a flexible and efficient concept for building new collaborative applications and services in All-IP networks. Our prototype applications on Symbian platform for mobile file sharing, navigation and sports have demonstrated the feasibility of the concept. In the future, application interactions can benefit from middleware support for optimized access to the heterogeneous All-IP networks and IMS service platform. The concept is also extendable to context-aware and presence-oriented mobile applications. Advanced algorithmic and heuristic approaches related to the state-machines can be further considered.

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