A Distributed Dynamic Mobility Architecture with Integral Cross-Layered and Context-Aware Interface for Reliable Provision of High Bitrate mHealth Services

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Abstract. Mobile health (mHealth) has been receiving more and more attention recently as an emerging paradigm that brings together the evolution of advanced mobile and wireless communication technologies with the vision of "connected health" aiming to deliver the right care in the right place at the right time. However, there are several cardinal problems hampering the successful and widespread deployment of mHealth services from the mobile networking perspective. On one hand, issues of continuous wireless connectivity and mobility management must be solved in future heterogeneous mobile Internet architectures with ever growing traffic demands. On the other hand, Quality of Service (QoS) and Quality of Experience (QoE) must be guaranteed in a reliable, robust and diagnostically acceptable way. In this paper we propose a context- and content-aware, jointly optimized, distributed dynamic mobility management architecture to cope with the future traffic explosion and meet the medical QoS/QoE requirements in varying environments.

Keywords: eHealth, mHealth, reliable and scalable mHealth service provision, DMM (Distributed and Dynamic Mobility Management), cross-layer (X-layer) design, context-awareness, content-awareness mobile IPv6 protocol family.

1 Introduction

Being part of modern telemedicine – which generally offers higher diagnosis and treatment quality standards, reduces medical costs, and provides possibilities to handle problems of the aging human society [1] – mHealth rises in parallel with the rapid adoption of mobile communications, computing, and advanced wireless technologies into our daily life. New, immersive, multimedia-driven, pervasive and interactive mHealth services (like self-diagnosis and preventive care [2], mobile-assisted telerehabilitation and therapy [3], medical care in emergency situations [4], etc.) are rising to provide timely and prompt medical attention while also saving monetary resources. The wide variety of promising application areas together with the

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continuous growth in consumer use of mobile Internet to obtain health-related services help the novel paradigm of mHealth in reshaping healthcare.

However, like other services running in mobile and wireless environments, the efficiency and usability of mHealth applications are substantially impacted by the continuously varying environmental characteristics, scarce network resources, sparse radio bands and bandwidth, fluctuating delay, jitter and other QoS parameter values. This clearly implies the need of context- and content-aware mechanisms making applications, service provision and delivery procedures adaptable to the extremely diverse mobile environments [5]. The impacts of fluctuations in context and resources are further aggravated by the current trends that prognosticate a massive traffic volume growth in mobile telecommunications during 2011-2020 [6]. To date, this traffic explosion is mostly driven by Internet applications providing interaction, information, and entertainment for human users. But with the widespread deployment of sensor technologies, another form of communications called M2M (Machine-to-Machine) is emerging which supposedly will be the leading traffic contributor for mobile Internet evolution [7] and also has the potential to become a major enabler of successful live mHealth deployments [8]. Another prominent force in mobile traffic growth is the advancement of high bitrate data-hungry multimedia applications: television/radio broadcasting and high-definition Video on Demand will increase mobile video volumes with 25-fold between 2011-2016, accounting for over 70 percent of total mobile data traffic by the middle of the decade [6]. This trend is also substantial in mHealth: the spreading of multimedia technologies and developments in mobile connectivity gives doctors and medical institutions a new set of tools for managing patient care, using high definition 2D/3D imaging for diagnostic purposes and providing new types of multimedia services, such as multi-view, stereoscopic and holographic video communications for tele-diagnosis and remote operations.

The high requirements of diagnostically useful multimedia transmission techniques and the thriving traffic demands pose serious research challenges for mobility architectures of mHealth [9] [10]. In this paper we propose a novel, jointly optimized mobility architecture for the challenges: the concept of distributed dynamic mobility management (DMM) is employed to cope with the growing traffic demands, the appropriately chosen and integrated protocol components solve various handover, security and multi-access issues, while the naturally integrated cross-layer design with high adaptivity based on context- and content-awareness helps to handle varying environmental resources and meet the medical QoS/QoE requirements.

The remainder of the paper is organized as follows. In Section 2, we introduce the related work on the existing solutions for challenges of emerging mHealth applications. Section 3 introduces our design choices and the main protocol components of the system. Section 4 in turn details our proposed integrated mobility management architecture together with the API framework created for supporting sophisticated cross-layer control and flexible adaptation. In Section 5 we conclude the paper and describe our ongoing work and future plans.

2 Related Work

To address the dynamic and fluctuating nature of mobile networks, the paradigm of context- and content-awareness started to emerge [11] [12]. The change in the context (i.e., in any information that can be used to characterize the situation of a mobile entity) or in the content (i.e., in any parameter classifying the media under transmission) would require e.g., to move specific users to alternative access networks [5] or to assign different security measures/interfaces for specific contents during mobility events [13]. However, being context- and content-aware requires an extremely flexible session and mobility management in a deeply integrated network support system. This can be achieved only with the elimination of strict boundaries between traditional layers of the communication model by introducing cross-layer design solutions that allow transport dynamic information between layers and provides jointly optimized operation for devices in wireless environments [14] [15].

The application of the above introduced advanced methods for mHealth applications has already been started. Jong-Tae Park et al. [16] presented a context-aware handover architecture for u-healthcare services in converged wireless body- and local area networks, which focuses on power efficiency. P.K. Gkonis et al. [17] designed a content-centric future Internet platform that supports added value health services (safe and accurate management of medicine prescriptions) incorporating mobility, context awareness, enhanced security and privacy. In the work of Yan Zhang et al. [18] the application of integrated WiMAX and WLAN broadband wireless access technologies for telemedicine services and the related protocol issues have been discussed together with some potential deployment scenarios. R. S. H. Istepanian et al. [19] focuses on medical QoS applied to a typical bandwidth demanding mHealth application, and proposes a novel multiobjective and adaptive rate-control mechanism for optimized delivery of diagnostically acceptable ultrasound video images over beyond 3G networks. V. Ghini, et al. introduced the m-Hippocrates software architecture [20] aiming to provide mHealth applications with constant and reliable communication using an application-level communication technology called Always Best Packet Switching (ABPS). This scheme ensures continuously available, reliable and interactive communication, but it does not consider advanced IPv6 based technologies for vertical handover support and relies on a solution, which is outside of current standardization activities.

However there are several enhancements of mobility management for mHealth applications in the literature, none of them take into account the exploding traffic demands and scalability issues of future wireless systems. Taking care of scalability problems by distributing mobile network functions and sharing the increased traffic load among the distributed elements is really a hot research topic nowadays. Several architectural improvements of existing technologies (e.g., [21]) or even green field solutions (like [22]) follow this approach, but all of them share the same issue: in such schemes it is essential to implement service continuity between the highly scattered internet points of attachment. To solve this, distributed and dynamic mobility management approaches must be envisaged [23].

In the traditional MIPv6 mobility scheme [24] all signalling and data packets are transferred via the central anchor node called Home Agent (HA).

As a first alternative for eliminating this centralized way of operation researches started to implement core-level distribution procedures: anchors are distributed but still remain in the core network. A good example to this is the Global HA to HA protocol (GHAHA) [25], which extends MIPv6 in order to remove its link layer dependencies on the Home Link and distribute the anchors at the scale of the Internet. The drawback of this design is the extreme load of the synchronization messages. The scheme of M. Fisher et al. handles this problem by distributing the Binding Cache [26], but their proposal is not implementation ready, as it does not specify mechanisms for data corruption, and HA failures.

A second alternative is when mobility functions are distributed in the backhaul and access part of the network. The multi-level system of Hierarchical Mobile IPv6 (HMIPv6) [27] and its extension proposed by Mei Song et al. [28] defines regions, in which the movement does not need binding at the Home Agent counter to the inter-region movement. It relieves the HA from the load of signalling, but it could be effective only for short-term sessions, or localized movements.

A third type of distribution scenarios is the so-called host-level (peer-to-peer) distributed mobility management where once the correspondent node is found, communicating peers can directly exchange packets. MIPv6 also uses this direction when it bypasses the HA thanks to its route optimization mechanisms [24] [29]. End-to-end mobility management protocols working in higher layers of the TCP/IP stack such as Host Identity Protocol [30] can also be efficiently employed in such schemes.

Another class of distributed mobility management is based on the capability to turn off mobility signaling when such mechanisms are not needed. The so-called dynamic mobility management schemes (like [31], [32]) dynamically execute mobility functions only for cases when Mobile Nodes (MN) are actually subjected to handover events and higher layers require address continuity. These architectures are session-based contrarily to the conventional mobility architectures, which provide the same mobility features for all of the sessions. It is not effective for long-term sessions and does not provide global reachability for Mobile Nodes, but it provides effective and on-demand resource distribution for short-term sessions.

In order to have a scalable, generic, secure, transparent and widely useable mobility architecture for mHealth services, we propose an IPv6-based, DMM- and implementation-ready solution, which focuses on the context- and content-aware operations, cross-layer optimization and integration of standard components.

3 Design Considerations

While almost all existing DMM proposals introduce new protocols and architecture, Basavaraj Patil et al. stated in their recent work [33] that *"(...) most of the needed basic protocol functionality for distributed mobility management is already there. What is missing seem to be related to general system level design and lack of mobility aware APIs for application developers"*. We share this vision with them and believe that appropriate and comprehensive integration of existing Mobile IPv6 building blocks could efficiently solve all the emerging mobility issues of current architectures. However, appropriate selection and integration of protocols is needed.

In our architecture proposal, the components were selected based on practical necessities and strictly focusing on implementability. All of them extend the original Mobile IPv6 core [24]. The most common extensions are Network Mobility (NEMO-BS) [34] which ensures the mobility of networks, and Multiple Care-of Addresses Registration (MCoA) [35] that brings the possibility of parallel usage of multiple network interfaces. Table 1 summarizes the main protocol components and their purpose, and this section details the connection of them with the DMM requirements.

The problems of low scalability and single point of failure are handled by *Hierarchical Mobile IPv6* [27] and *Global HA to HA* [25]. As we described, there are some drawbacks of them when applied alone, but their integration will result in a three level (top-level, mid-level, no mobility), distributed system with high flexibility and wide scalability options. GHAHA operates at the top-level by the global distribution of Home Agents. HMIPv6 reduces signalling overhead of the central network by defining the mid-level. Movement inside these micro-mobility regions are hidden from the central network, which could relieve the HA. However, these components do not solve the problems of non-optimal routes and high latency. That is why *Source Address Selection* [36] (SAddrSel) and *Enhanced Route Optimization* [29] (ERO) are also integrated in our scheme: these two techniques are specifically addressing routing and latency issues. ERO reduces signalling requirements of correspondent binding and makes it much faster. It could increase the efficiency of route-optimized traffic, which reduces the overhead of the central network. (Note, that for NEMO cases, on the Mobile Network Node (MNN), this API is not defined yet. A new interface will be necessary which could receive commands from the MNN, not only from the Mobile Router.) SAddrSel brings the option for the applications to optimize their sessions, and direct their traffic via the actual Access Point (AP, no mobility), the Mobility Anchor Point (micro- or mid-level mobility) or the Home Agent (macro- or top-level mobility). These options select the level of mobility and stability of the sessions according to the context of the usage in a dynamic and flexible way.

Table 1. Specifications to be employed

Name	Description	Purpose
MIPv6	Mobile IPv6 [24]	Core
NEMO	Network Mobility [34]	Core
MCoA	Multiple Care-of Addresses [35]	Core
HMIPv6	Hierarchical Mobile IPv6 [27]	Scalability, single p. of failure, distrib. op.
GHAHA	Global HA-HA [25]	Scalability, single p. of failure, distrib. op.
SAddrSel	Source Address Selection [36]	Signalling, RO, dynamic op.
RO	Enhanced Route Optimization [29]	Signalling, RO
FB	Flow Binding [37]	RO, X-layer opt., content-awareness
FMIPv6	Fast Handover for MIPv6 [38]	X-layer opt., handover speed-up
MIH	Media Independent Handover [39]	X-layer opt., handover speed-up

Two key features in our architecture further exploit the benefits of cross-layer optimization. The first one is the on-demand content-aware per-flow (per-session) route selection. It could be handled via the explicit and responsive selection of the anchor point (AP, MAP, HA) with the previously introduced SAddrSel feature. If there are multiple interfaces in the system, it could be extended with the selection from them. We should exchange the routing policies between the participants to ensure the correct routing of the backwards communication. It is solved with the help of the *Flow Binding* [37] protocol extension. Flow Binding extends the Binding Update messages to be able to synchronize the session directing rules on the MN and on the HA. The architecture should define the proper API commands to receive application interactions, and the environment should be synchronized. It does not have any effects on other components.

On the other hand, we could also optimize the (speed) of the handover processes by taking advantages of cross-layer solutions and such adapting to different network characteristics. Here we rely on handover preparation, initiation and decision schemes, like the *Media Independent Handover* (MIH) specification [39]. MIH has been designed to enable the handover of IP sessions from one Layer 2 access technology to another, to achieve mobility of end user devices. Our architecture will use MIH services and message exchange technologies to predict handover events and prepare handover executions. To be able to use the complex set of functionalities of MIH, the mobility management architecture should provide the appropriate handover execution mechanisms to make the handover faster based on the MIH operation. It could be realized by the integration of *Fast Handover* (FMIPv6) [38] protocol. Integration of FMIPv6 and HMIPv6 for appropriate mid-layer (MAP) operation has not specified yet, although there are non-standardized specifications (like [40]). Integration of MIH with the other components is handled via the FMIPv6 protocol: it lets a socket open for gathering context information to initiate handovers and the context information will be provided by MIH. The interoperability between FMIPv6 and MIH is not defined yet, but there are multiple results about this subject (i.e., [41]).

Fig. 1-A depicts the supposed interoperability between the previously listed protocols. The 'stick' sign means, that the components are compatible with each other. The interoperability process is directly or indirectly defined by RFCs. The 'warning' sign denotes questionable interoperability.

4 The Proposed Architecture and Cross-Layer API Framework

The key mobility management features of our architecture are integrated into a central module called the Mobility Management Daemon (MMD). However, some additional tasks, which are traditionally managed by other tools, are realized by external resources. The Router Advertisement Daemon handles the router advertisement tasks [42], including HA and MAP advertisements [24] [27] as well. The IKEv2 Daemon is responsible for IKEv2 key exchange [43], especially for HMIPv6 mechanisms.

MIH is not included into the core, because of logical mismatch (MMD is responsible for signalling and routing, but not for handover optimization); the API (see later) connects it to the core daemon. The MIH module is responsible for the X-layer signalling exchange between the nodes with the information about the status of the connection, gathered from different layers. The result of this message exchange is forwarded to the MMD via its API, which analyses this information, and it will initiate handover if it could make the connection faster, cheaper or more stable.

Fig. 1-B depicts the preliminary architecture of the Mobility Management Daemon. The concept is similar to the Data View Control paradigm of GUI applications [44]. The Communication part sends and receives the MIPv6 signalling messages. In addition it handles the necessary ICMPv6 messages [42] [24] too. The Data plane stores and manages the Binding Update List, Binding Cache, and other data related to binding management. The Environment is responsible for setting up the routing rules. It handles all of the management tasks, which are necessary to route the data packets to the right interface with the correct source address. The Control element manages the non-signal driven functions, for example expiration of different kind of entries. These parts don't possess direct interfaces to each other. Instead, an Internal Communication Bus (ICB) connects them. Some of the commands, which are available on the ICB, are exported for third parties through the Low-level Management Socket. An external, High-level Mobility Interface, which handles more complex operations, is also available. Additionally some key features should be integrated in separate modules. For example, movement detection is one of the most important parts, and it could be realized in many ways.

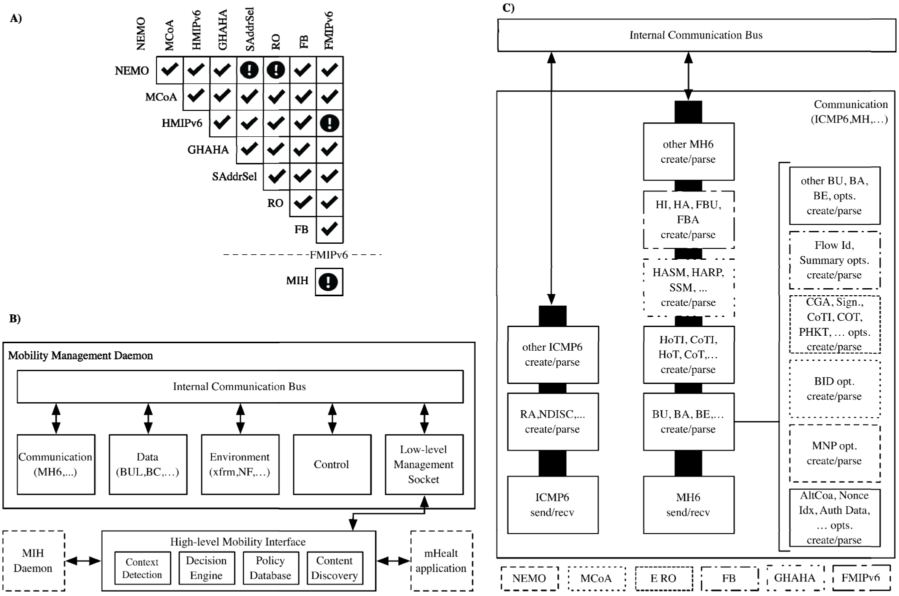

Fig. 1. A) Protocol compatibility chart; B) Proposed architecture of Mobility Management Daemon; C) Internal architecture of the Communication part

The above introduced architecture implements the core functionalities specified by [24], to which separate modules will be connected in order to integrate the wide scale of different protocol extensions to the base system. To better understand the modular architecture, we explain the details of Communication part (Fig. 1-C). While the communication core realizes the sending and receiving of ICMPv6 and MH6 messages [42] [24], the creating and parsing of different kind of messages is implemented by the modules, which belong to different protocol extensions.

Sending and receiving primitives for Mobility (MH) and ICMPv6 messages are essential for signalling functionality. The core protocol [24] defines the basic set of messages. Binding Update (BU), Binding Acknowledgement (BA) and Binding Error (BE) are indispensable for binding between the Central Network and the Mobile Nodes. Many options are defined for the Binding Update message. The most common Mobility Options are also defined in [24], but the others are specified by other protocol components like [34] [35] [37]. These options are to be inserted into the BU message by the corresponding extension modules; the core does not need to know about them. The architecture defines sockets for the modules to add further options or data to the messages before sending via handles. These should be executed at the corresponding point during the message preparation, and these could extend or re-design the messages before sending. Same as the core, all of the modules could define their own MH messages (e.g., global HA-HA's special signalling packets).

To make the MMD as powerful as it could be, it should continuously interact with the applications and other resources. A two-level API framework (Fig. 1-C) realizes this. On one hand, MMD integrates a raw interface, called Low-level Management Socket, which provides basic commands. The watchful selection of the implementation could solve the current problem between NEMO and SAddrSel (namely the lack of policy messages between the MNN and the Mobile Router). On the other hand, the High-level Mobility Interface at the top of the Management Socket realizes more complex functionalities and provides a simple API for the context- and content-aware services and specific X-layer optimization procedures.

The High-level Mobility Interface is a mid-layer between the Management Socket and the applications. It groups multiple command primitives into simple instructions, and integrates a decision engine, which provides easy to use QoS/QoE-centric control of handovers for context- and content-aware operations. This interface connects to the MIH daemon as well, and collects interface, media and other context information, which could help for the decisions. The decision engine also uses the policy database, which helps to find the best policy for the content within an actual set of environmental parameters. This application-driven, context- and content-aware API framework also brings the dynamic behaviour into our mobility management architecture: the top-level (HA) and mid-level (MAP) networks could be bypassed with on-demand binding, and the MN could perform binding only if it is necessary.

5 Conclusions

The proliferation mobile Internet applications and services tend to radically overload the current mobile and wireless architectures deployed nowadays. This traffic explosion will make the communication slower, less reliable, and also will pose serious problems for mobility management, which is essential for modern mHealth applications. To fulfil the special reliability, QoS/QoE, and bandwidth requirements of the mHealth sector, we should distribute the mobility management, and we should optimize the flow routing between the peers. The recent mobility solutions have to apply the features defined by DMM and have to integrate various optimizations, such as cross-layer optimization, context- and content-awareness. Our proposed architecture is a promising, standard-based, implementable and integrated answer for all the issues of current Mobile IPv6 systems also within the unique context of mHealth use-cases. We are currently working on the implementation [45] of the proposed architecture, which will be followed by the functional validation and the performance evaluation of our design in real-life testbed scenarios.

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