A Novel Hierarchical Group-Based Overlay Healthcare Network

Foteini Andriopoulou, University of Patras, Patras, Greece
Konstantinos Birkos, University of Patras, Patras, Greece
Dimitrios Lymberopoulos, University of Patras, Patras, Greece

ABSTRACT

In the healthcare domain, there is a challenge on how to design a scalable, dynamic, robust and secure network for provisioning personalized healthcare services remotely with an efficient and accurate manner. In the present work, motivated by innovations in the networking domain and the benefits of clustering in the peer-to-peer networks as well as the group-based approach of the social networks, we propose a novel hierarchical peer-to-peer overlay healthcare network for communication and collaboration among healthcare professionals, paramedical staff and patients. The proposed network includes two types of hierarchy: the first type is used for regular requests and communication while the second type handles emergency requests. The network architecture is based on multiple and enhanced structured overlays that provide scalability, dynamic features, load-balancing and low response times with guaranteed information retrieval. Moreover, a novel and effective lookup mechanism supports complex queries with significantly lower response time and messaging overhead.

KEYWORDS
Complex Search, Group-Based Networks, Healthcare, Hierarchical Overlay, Peer-To-Peer Networks, Self-Organized Networks

INTRODUCTION

Advances and innovations in the ICT domain have enabled the healthcare environment to provide personalized services (e.g. tele-monitoring, tele-medicine, appointment scheduling etc.) remotely to patients and other participants, i.e. doctors, nurses, paramedical staff that are involved into the treatment plans. The increased demand to handle vast amounts of information and provide accurate treatment efficiently and dynamically poses new challenges to the existing communication infrastructures and networks. These challenges cannot be fully addressed by general-purpose information systems since they do not take into consideration the combination of complex requirements of the healthcare domain such as accurate information searching and retrieval, the dynamic nature of the participating users and appliances and large-scale deployment. The existing systems seem to be inappropriate and inefficient for the ubiquitous healthcare environment. Centralized systems exhibit poor scalability as the number of users and the requests for information retrieval increase. Moreover, in large-scale centralized systems, the increased complexity of information retrieval leads to single points of failure and creates many problems known as bottlenecks. In the healthcare domain, these impairments are crucial in patient’s treatment and pose patient’s life at risk in critical conditions. From this point of view, there is a need for scalable, dynamic, robust and secure networks oriented to healthcare purposes.
The peer-to-peer paradigm seems to be the most fertile computing approach to address the previous challenges. Peer-to-peer networks are characterized by distributed, self-organized, scalable, robust and dynamic functionalities that suit well to the prerequisites of the healthcare domain. Recently, some research efforts have proposed healthcare solutions based on the principles of peer-to-peer networking (Geissbuhler, Spahni, Assimacopoulos, Raetzo & Gobet, 2004; Kailasam, Kumar & Dharianipragada, 2010; Maglogiannis, Delakouridis & Kazatzopoulos, 2006). These works are limited either to a theoretical level or they focus on specific aspects like file sharing. They usually rely on existing structured topologies that offer enhanced scalability and they are particularly effective in handling simple queries. However, they do not inherently support complex queries and the maintenance of the overlay structure requires additional computational cost and message exchange, especially in large-scale networks. On the other hand, unstructured overlays can withstand frequent connections and disconnections of users and they can handle complex queries. Nevertheless, their main search mechanism is flooding which causes increased message overhead and they perform poorly when handling simple queries or when searching for rare items. Given the nature of the medical information stored and exchanged through a healthcare network, support for both simple and complex queries is mandatory. Moreover, for accurate treatment, guaranteed information retrieval with low response time is significant. Structured peer-to-peer overlays are more suitable as the basis for the development of novel peer-to-peer networks tailored to the needs of healthcare systems.

In this work, we propose a novel hierarchical group-based peer-to-peer overlay network for healthcare purposes. This hierarchical network is based on multiple structured peer-to-peer overlays based on Distributed Hash Tables (DHTs) as they provide scalability, dynamic features, load-balancing and low response times with guaranteed information retrieval. However, the functionalities of the structured overlays are enhanced with mechanisms for security, locality and information lookup with multiple criteria. Locality is achieved by organizing users into groups according to their common geographical zones, roles and interests. This group-based approach improves the performance of the system since the requests are propagated in a smaller number of participants. The lookup functionality is realized by means of a novel mechanism based on controlled flooding that exploits the existing structure of the overlay network. This mechanism is characterized by low response time and low messaging overhead. Apart from the hierarchical structure that facilitates administration and security policies, security is based on set of mechanisms like digital certificates, symmetric cryptography and asymmetric cryptography and trust establishment among participating users. Moreover, two types of hierarchy are introduced. The first type of hierarchy is used for regular requests and communication while the second type of hierarchy handles emergency requests in an effective and timely manner. The performance of the proposed network has been evaluated through a series of simulations. The results verify the scalability and the effectiveness of the applied mechanisms in terms of response time and number of queries. Both hierarchical models exhibit high scalability and they are effective in retrieving rare pieces of information. The hierarchy model used for emergency cases can reduce the response time significantly.

RELATED WORK

During the last decade, the growing benefits of peer-to-peer approach have gained the attention of the research community for deploying peer-to-peer networks according to the healthcare requirements. Geissbuhler et al. (2004) provided a conceptual idea of peer-to-peer for information sharing among multiple heterogeneous institutions. Maglogiannis et al. (2006) proposed a web-based application that enables medical professionals to exchange Electronic Health Records. The VIRGO network (Huang, 2005) was implemented to support doctors and academic institutes to share complicated information providing semantic interoperability through a prefix mechanism according to the institution, department and name of the information. Finally, Kailasam et al. (2010) proposed a network for healthcare purposes based on multiple zone overlays in order to search with an efficient
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