Abstract—This paper presents a high-level overview of the CareNet Home Extension Project that aims to provide support for home-based healthcare for the elderly and outpatients. Details of a home networking environment based on a virtualized Residential Gateway (RG) are provided. The RG architecture is modular and scalable supporting the dynamic provision of third party services. This accommodates multiple independent stakeholders representing healthcare providers, Internet Services Providers (ISPs), and home automation system builders among others. Interoperability is guaranteed through adherence to open standards.

Initial mechanisms facilitating the integration and consolidation of in-home systems, whilst providing a flexible framework for autonomous management, are described. This addresses issues of management and configuration of complex environments by individuals with little or no technical expertise. Finally, details of an initial implementation, in terms of architectural descriptions and enabling technological components, are outlined.

Index Terms—Autonomous Networking, Multi-Agent Systems, OSGi, Residential Gateway, Virtualization.

I. INTRODUCTION
HIS paper presents initial results of the CareNet Home Extension project [1] sponsored by Vinnova [2], the Swedish government agency for research and innovation. CareNet is an advanced research network infrastructure in Stockholm, Sweden. It is a collaboration between centers of academic excellence and the industry. Participating academic institutions include: KTH - Royal Institute of Technology [3], Sweden's premiere technical university and Karolinska Institute [4], Sweden's largest medical university. This project is part of a multi-stakeholder effort that is targeted at transforming the delivery and quality of healthcare to elderly people and outpatients.

Technological innovations are giving rise to new lifestyles and changes in behavior. The Internet is one such innovation. Today the availability and abundance of Internet connectivity in the homes and the proliferation of networked devices is overwhelming. Technology is increasingly being employed to assist us in living safer, healthier and more ecologically friendly lives. This is affecting every facet of life including the delivery of healthcare. Christensen in [5] highlights technological enablers for healthcare. These included improved molecular diagnostics, advanced imaging capabilities and high bandwidth telecommunications.

The Telecommunication Systems Laboratory's (TSLab) [6] is using its knowledge and expertise in networking technologies to develop solutions for healthcare. Over the last decade TSLab has been involved in numerous projects that addressed different aspects of healthcare delivery. Through the CareNet Home Extension project, TSLab is exploring extensions of healthcare into patient's homes.

The purpose of this paper is to present ongoing work in the realization of an open computing infrastructure for the deployment of home-based healthcare services. Specifically, this work addresses the design of Residential Gateways (RGs) carried out in the CareNet Home Extension Project. The rest of this paper is organized as follows: section 2 gives an overview of home-based healthcare and highlights some of its key motivators. Related work in the area of RGs is presented in section 3. Section 4 details the requirements of the CareNet RG. Then section 5 describes the conceptual architecture of the CareNet RG. Finally, a brief summary of the paper is presented in section 6.

II. HOME-BASED HEALTHCARE
As a prelude, we discuss some of the issues related to home-based healthcare. Some relevant motivators are presented and key technological enablers are outlined.

A. Motivators for Home-based Healthcare
Home-based healthcare is steadily gaining popularity, not only due to an aging population but also due to an increased demand to provide healthcare in homes of patients [7]. The frail, elderly and disabled prefer assistive technologies and in-
Home network environments have grown both in popularity and complexity. The increase of broadband connectivity in homes and the wealth of information that can be sensed, even from ordinary consumer electronics available in the homes, is phenomenal. Modern homes today typically have a number of systems ranging from security systems, zoned environmental control systems, energy management systems and multi-room audio/video systems. This coupled with the available computational power in most modern homes present numerous opportunities to develop innovative technologies that can really impact our lives. These heightened levels of automation are driven by a demand to make living spaces more ecologically friendly. In the coming decade, we can expect to see an even greater drive as demands from healthcare dramatically increase.

**B. Issues and Challenges in Home-based Healthcare**

The above technological enablers and trends point towards an evolution in the structure and delivery of health care services. Though the move towards increased home-based care is inevitable, developing technology for the home and for home users is not simple or straightforward. Homes are complex environments with demanding users that have exacting requirements and specifications. In order for technology to be effectively deployed in, and adopted for, home-based care, it must not pose many restrictions on its end-users. Rather the technology needs to intelligently adapt to user requirements adding value to, and simplifying, their lives in the process.

As home network environments evolve to support richer interactions and additional functionality, the complexity in configuring and managing them increases proportionally. This complexity grows significantly with the inclusion of medical monitoring equipment. Such equipment may demand better Quality of Service (QoS) and higher resource prioritization than other networked devices in the home. This requires that network access, to all devices in the home, is managed centrally through predefined policies and preferences. Concurrently, security requirements of in-home systems are augmented through such integration and consolidation. However, achieving adequate levels of security in a home without imposing strict changes in lifestyles of home occupants is not a trivial task.

Furthermore, systems available in homes are often diverse and incompatible making them hard to integrate, manage and use effectively. This heterogeneity and the lack of widely accepted standards is fueling a haphazard growth in home automation. The design and implementation of systems, currently in use today, are often proprietary and deployed on purpose-built embedded systems. This can greatly limit interoperability which can hamper the seamless integration of such systems in the future. Though many systems can now be configured through a web interface, there is still a need to have systems that can collaborate, share context information and be controlled through a single unified interface.

**C. The Role of a Residential Gateway in Healthcare**

All the issues and challenges outlined in the previous section advocate the integration of in-home services. An RG is essentially a demarcation device between the home network environment and an operator’s network. It therefore controls internal and external network access. Its role therefore, can easily be elevated to include managing and orchestrating the operations of the different systems available in the home. This does not exclude, healthcare monitoring equipment deployed in the home.

An integrated RG can have a catalytic effect on the development of in-home services including the provision of home-based healthcare. Such a device would be essential in ensuring connectivity between a hospital and its home-based patients. The RG could provide a single point for configuration, policy enforcement, management and control. RGS can also support the dynamic execution of third party services. This would allow Internet Service Providers (ISPs), Content Providers, Triple-Play Providers as well as home automation system vendors, home security system vendors and healthcare providers to be hosted on a generic service execution platform.

In the long term, we envisage a trend towards the commoditization of medical domain knowledge and expertise. This is supported by an increased interest in Decision Support Systems (DSS) [8] for healthcare and clinical practice. We predict that this will lead to a proliferation of medical appliances providing pre-trained clinical decision support or medical advice to in-home patients. These appliances will be able to collect and process medical data on its subjects and communicate abnormal conditions to nurses, doctors or emergency medical personnel. An RG would be an ideal candidate to provide an execution platform for such appliances and could play a pivotal role in their wide spread adoption in the future.

**III. RELATED WORK**

In this section we highlight some of the previous work that is related to this project. Residential Gateways (RGs) have
been a subject of much interest from both industry and academia for the last decade. An RG's primary role is to mediate between a residential network and a service provider's network. Hofrichter in [9] however, presents an RG model that supports the dynamic provisioning services. This enables a service provider to remotely manage and administer the services that they deliver to a home. We concur that dynamic service provisioning, and a Service Oriented (SO) approach, is a key element in the realization of future home-based care services.

Open Service Gateway Initiative (OSGi) has been extensively used in the implementation of RGs [10], [11] for its modularity and support for dynamism within RG architectures. However, the lack of resource prioritization and consumption management features makes OSGi unsuitable for healthcare applications. Ibanez et al. introduces virtualization to achieve concurrent, yet exclusive, management of OSGi platforms executing on an RGs [12]. Virtualization can also address the lack of resource prioritization by placing resource constraints on an OSGi platform thereby ensuring that mission critical applications, such as healthcare applications and security systems, have adequate resources reserved for them at all times.

However, virtualization adds an additional layer of complexity to OSGi. By isolating the different OSGi services onto separate OSGi platforms, support for dynamic service registrations in OSGi, is lost. As of this writing OSGi does not support distributed platforms. Though R-OSGi [13], a distributed middleware platform extension for OSGi, exists it still does not provide capabilities for dynamic bundle matching.

Software agents have also been applied to the problem of home-based care in [14], [15], [16]. Agents are particularly suited for distributed systems and applications [17] that require coordination and collaborative problem solving. Work has already been done in interfacing agents with OSGi in [18]. Agents can address the distributed issues introduced by virtualizing OSGi platforms through intelligent interactions using a domain specific ontology. Furthermore, agents can exhibit intelligent behavior such as negotiation, learning and adaptability all of which can be performed autonomously by agents.

Though much work has been done in the area of RGs both from a service provider's perspective and for the delivery of healthcare in the home, a number of issues have not sufficiently been addressed. These include securing, configuring, and managing complex residential network environments by individuals with little or no technical expertise. Furthermore, to our knowledge, dynamically facilitating cooperation and collaboration between heterogeneous home systems to create smart environments has not been addressed.

IV. CARENET RESIDENTIAL GATEWAY REQUIREMENTS

In this section we present some of the key requirements for the CareNet Residential Gateway (RG). Previous attempts have been made to detail requirements for an RG. These have been presented by [19], [20], [21]. Rather than reproduce or duplicate their efforts here, we focus on requirements that are critical to the realization of the CareNet RG.

A number of pivotal building blocks are required to realize an intelligent Residential Gateway (RG) that can truly support home-based care applications. Most of the technologies required to achieve this are already available, albeit in piecemeal and often incompatible form. The major challenge is to achieve cooperation and coordination between these heterogeneous, and often autonomous, systems through open protocols and standards. Such integration needs to allow for the declaration of dynamic agreements, policies and procedures between disparate technologies allowing them to function both synergistically and seamlessly.

![Figure 1: Overview of CareNet Network.](image-url)

Figure 1 displays an overview of the CareNet Network. In the diagram the RG is responsible for coordinating the systems in the home, allocating resources to them dynamically based on predefined policies. The RG supports the dynamic provisioning of services. In this regard, Service providers can remotely deploy and manage services onto the RG. In order to achieve this the RG must fulfill the following requirements.

**Reliability & Robustness:** The RG consolidates mission-critical services such as security, energy management and home-based care. This places strict requirements on the system to be always on, always available and always operational. Its hardware must have a high Mean Time Between Failures (MTBF). The RG is additionally required to support multiple independent Internet connections and should continue to operate, possibly with reduced functionality, when no Internet connection is available.

**Intelligence / Reasoning:** The RG must exhibit some form of intelligence or problem solving capabilities. This is essential for multi-provider environments. The RG must therefore be able to detect conflict conditions that arise and adapt accordingly. Fail-safes should exist that ensure the safe operation of in-home systems and home-based healthcare...
monitoring devices even in adverse conditions. Lastly, the RG must be capable of recognizing patterns in behavior and perform some elementary forecasting.

**Scalability:** As the number of electronic communication devices in the home grows, the role of the RG will become pronounced. The RG must therefore scale to meet the demands placed by additional networked devices as well as an increase in the number of service providers delivering services to the home through the RG.

**Security:** Security of the RG needs to be adequately addressed through strong authentication and authorization schemes. The RG should provide comprehensive data privacy and protection through encryption mechanisms. Lastly, all communication between a service provider and the home, especially in the case of hospitals, need to be established using secure channels such as IPSec and VPN tunnels.

**Usability & Simplicity:** Home services must be simple and intuitive to be useable by ordinary users with limited technical skills. Specifically for medical purposes, the user must be able to get access to the medical data recorded and be able to grant access permissions to third parties if desired. Finally, the RG may also be required to support interaction with users having specific impairments.

**Upgradability / Dynamism:** Software and services deployed on the RG must be easy to install, maintain and upgrade with a minimum end-user involvement. Apart from remote management the RG should be capable of autonomously managing itself, optimizing its performance and adapting to adverse conditions that arise.

**Open Standard technologies:** The RG should be based on open industry standard technologies so as to ease integration with third party systems seamlessly. All data stored on it should use existing data formats. Software utilized in building the RG should be, as much as is feasible, free and open source software.

V. **CARENET RESIDENTIAL GATEWAY ARCHITECTURE**

In this section we describe the overall architectural design of the CareNet Residential Gateway (RG). The architecture is based on open industry standards to ensure compatibility with existing and future systems. The gateway adopts a Service Oriented approach and, thus, accommodates the deployment of dynamic services. A Multi-Agent System Architecture (MSA) is employed to provide autonomous management and intelligent behavior.

Virtualization is used to isolate the services delivered through the RG. At the same time, virtualization is used to ensure exclusive access to resources. In this case a medical monitoring service may need to be granted exclusive access to a serial (RS-232) port for example.
In order to achieve high levels of integration and orchestration, a context brokerage service is provided to facilitate the exchange of contextual information between the producers and consumers of context data. The service also assists in the fusion of sensed context from multiple sources thereby both validating unexpected or faulty sensor readings and enhancing the sensed data. At the same time, the service serves as a single point of access for data archival and data mining functions.

**Configuration Service:** The configuration service implements a command and control as well as Graphical User Interface (GUI) for users to interact with the services provided in the home. This allows the user to configure all of the available services in the home through a simple front-end. The configuration service transparently translates the input provided into corresponding configurations, policies and access control lists.

**Management Service:** The Management Service is the core service of the proposed RG architecture. It provides life-cycle management of service bundles executing on the RG. It additionally is responsible for autonomously managing and orchestrating the operations of the RG.

**B. System Services**

The MC hosts a number of system services that a hosted SC can take advantage of. These include local network services, secure file transfer, web servers, Dynamic Host Configuration Protocol (DHCP) servers, Domain Name Servers (DNS); SNMP server. Additionally a Java Virtual Machine (JVM) and agent execution environment are also available as system services. Other services such as security and management services, including firewall, scheduler, Bandwidth Manager (BWM), provide protection and prioritization of resources allocated to the hosted service platforms.

**VI. SUMMARY**

In this overview paper, we summarized the conceptual architecture of the CareNet Residential Gateway. A description of the RG architecture was presented with emphasis on the integration of heterogeneous home network services and environments. Special emphasis is placed on facilitating autonomous management, adaptability and smart behavior to address security, management and configuration issues of converged home systems. While many aspects of this multidisciplinary project are still currently under development, the core technologies have been clearly defined. Current work is focused on realizing a proof-of-concept prototype that implements the concepts presented in this paper. Development of an application domain ontology that specifically caters for home environments is also currently underway.

**REFERENCES**


