Presented at the 6th International Conference on Intelligent Environments (IE'10), Kuala Lumpur, Malaysia. 19-21st of July 2010


# STUDENT: Scenarios, Technologies & Users within the Digital Essex Network Testbed

K. Guild, M. Paredes Farrera, R. Martin, R. Almeida, A. Bontozoglou, M. Patel, K. Yang, V. Callaghan
University of Essex
School of Computer Science and Electronic Engineering
Colchester, UK
e-mails: kguild, mpared, rmarti, abodoz, mpatelp, kunyang, vic @essex.ac.uk

***Abstract*— The current status of a campus research testbed that is being constructed to allow for the exploration of digital service delivery and smart networked environments using different networking technologies is presented.**

***Keywords-intelligent smart environments; networked environments; networked digital services;heterogenous networks***

## I. Introduction

This paper gives an overview of a network test bed that is being constructed in order to create an environment that provides a platform for the multi-disciplinary exploration of digital service delivery and smart networked environments. The purpose of this paper is to highlight the main capabilities and experiments currently underway and to extend invitations to interested parties to utilize, extend and to collaborate within the testbed.

Although the main focus of this paper is on the Colchester campus network testbed at the University of Essex (UoE), the overall aspirations for a large-scale Digital Essex Network Testbed will be briefly outlined. With reference to figure 1, the Colchester campus testbed is connected via the UK's educational and research network, JANET [1] to the other campus site based at Southend-on-Sea. Plans for extending the research network such that the students and staff will also have access to the same services and applications as Colchester are in progress. The Southend-on-Sea council has currently deployed a community broadband network infrastructure that serves the 50 schools and colleges in the region using a Multi-Protocol Label-Switched (MPLS) gigabit backbone. Plans for extending the networking infrastructure to some of the 150,000 Southend-on-Sea inhabitants using Wi-Fi access points are underway. As part of a digital exploration center (DEC) concept funded by the East of England Development Agency (EEDA), a large-scale network test bed will be deployed in order to help regenerate certain areas by providing high-tech facilities and resources to local businesses. This is in conjunction with the local council, the regeneration company, Southend Regeneration Ltd, and the University of Essex. The testbed will include affordable high-speed symmetrical bandwidth that can be purchased on a pay-per-use basis, initially via wireless access. The DEC will also provide access to shared network, equipment and content resources and will be connected initially via a 150Mbit/s wireless connection to the University's Southend campus. Since JANET cannot be used to transport revenue-generating traffic, commercial backhaul bandwidth to the Internet will be purchased by the DEC in order to allow the experimentation of various business and service delivery models. The test bed aims to offer a "living lab" environment that will offer an open access network architecture that can be evaluated from technological, business and socio-economic points of view.

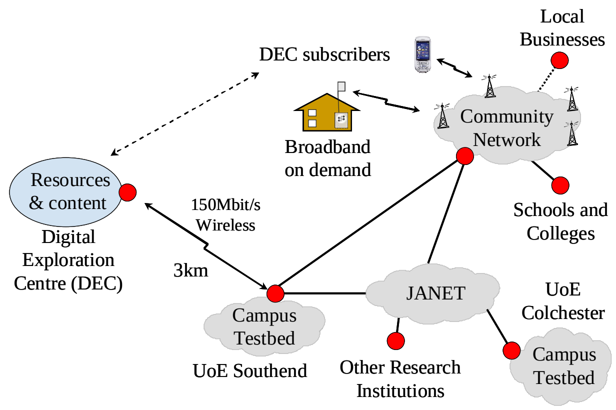


**Figure 1: Digital Essex Network Testbed**

## II. Infrastructure

The test bed was originally created to examine the end-to-end networking issues presented by the consumption of next-generation services over current and next-generation network technologies. To this end, a wide variety of networking architectures and technologies have been deployed in order to better understand and evaluate the networking issues and usage behaviors within an experimental research environment. Broadband fixed and mobile services are delivered using both fiber and wireless access network technologies. The majority of the testbed was developed within a nationally funded project called HIPNet (Heterogeneous IP Networks) that completed in 2009 [2]. The goal of the project was to address the issues of end-to-end service management in a heterogeneous networking environment. This effort lead to the development of a number of service and network models which were utilized within various network simulators to examine particular scenarios. In order to validate some of these modeling

Presented at the 6th International Conference on Intelligent Environments (IE'10), Kuala Lumpur, Malaysia. 19-21st of July 2010


activities with real services and users, a campus-wide network testbed was constructed at the University of Essex. These facilities will be briefly described in the following sections.

### A. *Wireless Access network*

A wireless research network has been created using a combination of the University's networking infrastructure and additions funded through research projects (figure 2). Over 120 of the University Access points (APs) across campus have been made available and provide an open unauthenticated service set identifier (SSID) called "iCampus". The traffic from the users that join this SSID is routed via a dedicated virtual local area network (VLAN) across the University fixed network infrastructure to the Network Convergence Laboratory (NCL). This offers a segregated open network access for staff, student and visitors through which research-based content and services can be delivered and evaluated. The "iCampus" VLAN is also the path for traffic originating from users accessing the testbed from the University fixed network infrastructure (eg from the student accommodation).

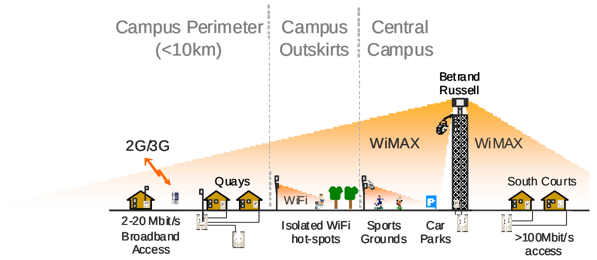


**Figure 2: Heterogeneous Wireless Access Network**

The testbed is used to evaluate dynamic backhaul of broadband wireless services and also Media Independent Handover (MIH) between heterogeneous wireless networks within such an environment. A WiMAX base-station provides directional 802.16 coverage and a backhaul path for isolated 802.11g Wi-Fi access points. 300Mbit/s broadband access is provided by 802.11n APs directly from an optical access network (see below). 2G and 3G cellular coverage is available across the whole campus.

The WiMAX basestation is mounted on the roof of a student accommodation tower (Betrand Russell) 65m above sea-level (Figure 3) and backhaul provided by the optical access network (section B). The deployed antenna system consists of a number of antennas providing a range of fixed and on-demand coverage. A single fixed 60° sector antenna, operating within the unlicensed 5.8GHz band, provides coverage to an area south of the University; this is a popular residential area for University staff and students and it is possible to provide up to 20Mbit/s symmetrical services to locations 2 miles from the tower. Independently, three 60° sector antennas are mounted on a motorized pan/tilt mechanism that allows coverage to be directed to various locations around campus and the surrounding areas. These antennas operated in the 5.8, 2.5 and 3.5GHz regions. Although only the unlicensed 5.8GHz antenna is currently in use, the licensed 2.5 and 3.5GHz antennas can be made available for future experiments for interested parties wishing to evaluate this part of the spectrum within the testbed. The pan/tilt mechanism is controlled via an application programmable interface (API), allowing its automated use for a number of different scenarios and applications. Currently, the position of the antennas can be directed by absolute GPS coordinates entered via a web interface, via mobile text message or point-and-clicking from within Google maps. The latitude and longitude values are converted into the appropriate pan and tilt values for the motorized antenna mount. The control of a dome surveillance camera works in a similar manner allowing the tracking of a user's GPS coordinates or to aid the positioning of the antenna array given the line-of-sight nature of the 5.8GHz signal. The camera also provides a continuous source of real-time traffic over the network to evaluate various quality of service (QoS) mechanisms in video transportation applications.

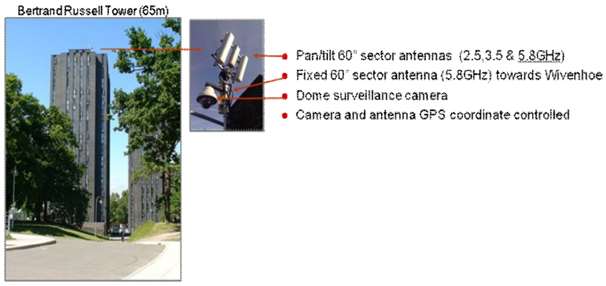


**Figure 3: WiMax basestation**

### B. *Optical Access network*

Using existing single-mode fibre (SMF), a fibre-to-the-home (FTTH) network has been deployed across campus using Gigabit Ethernet Passive Optical Network (GPON). Access to the testbed services and applications is via the VLAN that is also used to backhaul the wireless AP traffic. The GPON technology is upgradeable to 10Gbit/s in the future without changing the intermediate points since the splits are based on passive optical splitters. The fiber penetrates a number of locations across campus as shown in Figure 4.

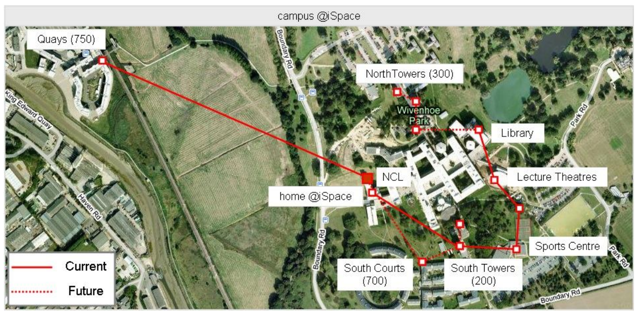


**Figure 4: Fiber-to-the-Home (FTTH) connectivity**

Presented at the 6th International Conference on Intelligent Environments (IE'10), Kuala Lumpur, Malaysia. 19-21st of July 2010


Currently, the fiber terminates at the base of each accommodation block at a GPON Optical Networking Unit (ONU). A Gigabit Ethernet switch provides 100Mbit/s Ethernet connections to the individual rooms. The number in brackets indicates the number of students that each accommodation block houses.

### C. *Core network*

Since an end-to-end homogeneous IP-based network is far from reality, a number of networking technologies have been included in the testbed as shown in Figure 5. The optical and wireless access networks and the VLAN from the campus network interface to the multi-service access nodes that bridge the traffic to the appropriate transmission layer. Both IP and Ethernet routers/switches offer packet-switching capability. Next-Generation Synchronous Digital Hierarchy (NG-SDH) cross-connects that are more data-friendly than traditional SDH cross-connects offer low-latency circuit-switched connections. NG-SDH is an important legacy technology to consider given that SDH technology is still going to be present in a large number of core networks for years to come. Optical circuit switching is achieved using three optical cross-connects (OXCs) which are able to switch Dense Wavelength Division Multiplexed (DWDM) wavelengths and thereby permit all-optical switching and dynamic network rearrangement in response to changing network usage patterns. Optical switches also allow optical “cut-through” of electrical switches/routers for long-lived large flows to reduce transit traffic through the electrical matrices; this can result in better end-to-end performance for real-time services and reduces the load on the electrical layer.

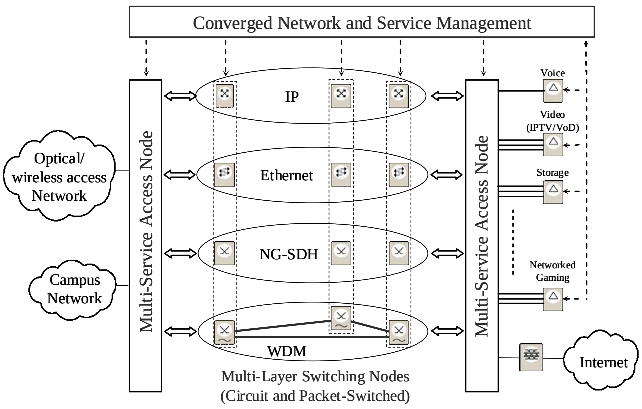


**Figure 5: Multi-layer core network**

Another multi-service access node connects the multi-layer network to the services and applications and the outside world via a firewall to the UK’s education and research network, JANET [1]. The latter also provides high-speed connectivity to other research institutions worldwide. A converged network and service management plane controls the hardware as described in the next section.

## III. NETWORK AND SERVICE MANAGEMENT

In order to manage and control the network infrastructure, a number of control and management functions have been developed as illustrated in Figure 6.

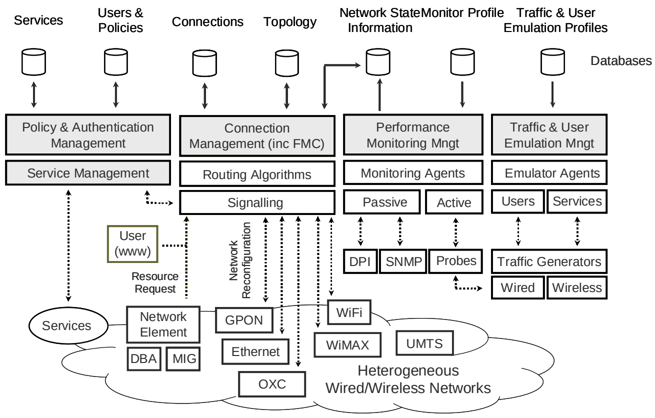


**Figure 6: Overview of network and service management**

### A. *Traffic and User Emulation*

In addition to real services and applications provisioned across the network, mechanisms for emulating traffic and users are also included. A number of traffic generators can be activated to mimic certain traffic scenarios for both the wired or wireless parts of the test-bed. Emulator agents are activated according to a pre-defined pattern as determined by the information stored in the traffic and user emulation profiles database. These features are primarily concerned with the network control for catering with extreme events and overload conditions and are used to evaluate the effectiveness of the QoS and dynamic bandwidth allocation mechanisms within the testbed. Through the observation of real users and usage patterns, various user models can be constructed.

### B. *Performance Monitoring Management*

This is a key element of any network architecture and a number of performance monitoring techniques are implemented and evaluated. Passive monitoring techniques, that don’t introduce additional traffic into the network, include packet-by-packet analysis using deep packet inspectors and standard network element interrogation through Simple Network Management Protocol (SNMP). Active performance measurement techniques include injecting probe packets into the network and measuring the performance either at different networks segments or on an end-to-end basis. There are a number of trade-offs associated with performance monitoring and these can be evaluated under different scenarios. The monitoring agents are activated according to the monitoring profile and the results stored in the network state information database.

Using deep inspection (DPI) of the traffic streams, the services can be policed and regulated according to different policies and network conditions. Figure 7 illustrates an

Presented at the 6th International Conference on Intelligent Environments (IE'10), Kuala Lumpur, Malaysia. 19-21st of July 2010


example of how peer-to-peer traffic can be suppressed at peak times in favor of web and audio/video traffic at the wide area network (WAN) of the campus.


**Figure 7: Monitoring of services using DPI**

Currently, the focus is on optimizing the network and ensuring adequate resources are provisioned to the different services in a mobile environment; in other words, QoS-aware mobile services. This relies not only on the correct selection of access points by a mobile client, but also on ensuring that the backhaul connection across the fixed network is adequate. This will become especially important in future 4G network deployments. The information stored in the network state information database is used to determine the most appropriate access point to be selected; if the backhaul path requires adjustment, this is done dynamically by the dynamic bandwidth adjustment (DBA) algorithms described below.

### *C. Connection Management*

The connection manager keeps track of all provisioned connections in the test-bed and uses the information in the network performance database to "police" the integrity of existing connections and also to determine the route computation based on certain constraints. Resource requests from either a web interface from a user, a network element or a dynamic bandwidth allocation (DBA) algorithm invoke the path computation engine (PCE) within the routing algorithm element. Figure 8 illustrates how dynamic bandwidth allocation applied at the WAN interface of the campus testbed can help minimize wasted Internet bandwidth by requesting "just enough" bandwidth from an ISP.

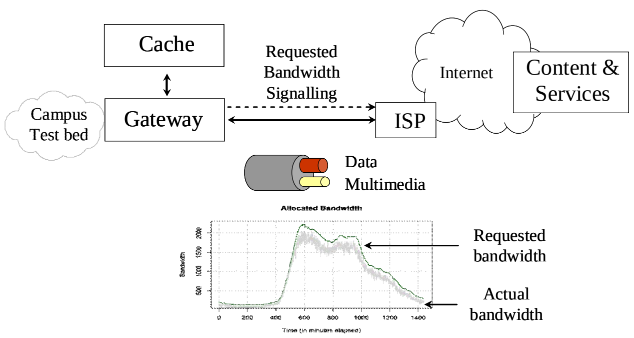


**Figure 8: "Just-enough" Bandwidth Allocation**

Combining this with local caching can result in significant savings in Internet bandwidth.

DBA encompasses a number of techniques and methods for the provision of sufficient bandwidth following an analysis of bandwidth profiles, user requirements, traffic priorities, and QoS guidelines [3]. In the example below, a Dynamic Bandwidth Allocation Algorithm has been tasked with providing just-enough bandwidth to satisfy the expected customer demand, which is evaluated through a Simple Network Management Protocol (SNMP) interface.

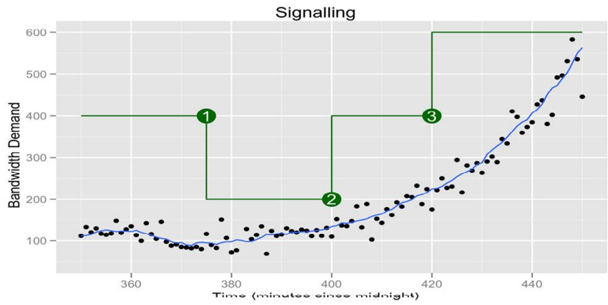


**Figure 9: Just-enough bandwidth allocation using dynamic bandwidth allocation algorithms**

In order to do so, it makes three signals to the ISP in order to effect step changes in the bandwidth provision as indicated by points 1 to 3 in figure 9. This guarantees that there is always sufficient bandwidth available for the traffic, whilst allowing spare capacity for unforeseen events. In the framework described in the introduction whereby the DEC acts as a broker of network resource, such DBAs will be necessary to optimize the allocation of Internet backhaul resource (potentially from a number of providers) to subscribing users.

### *D. Policy, Authentication and Service Management*

How to engineer cost-effective adaptive services that have the ability to run anytime, anywhere and on any mobile device is also a research challenge in such a hybrid network environment. While the current literature focuses on building up a powerful middleware infrastructure sensing the interesting contextual changes and adapting accordingly, our test bed has designed and implemented another means to provide service adaptability from another angle, i.e., the internal logic of adaptive service itself, which is largely neglected. The fundamental thought here is to grant the service, instead of its execution environment, the adaptability, leaving the execution environment as clean, simple and easy to deploy as possible. To this end, policies are utilized to describe the service logic at a higher level. Policies are also commonly used to fulfill security mechanisms.

A policy is employed to define a choice in the behavior of an adaptive service. For example, ***IF*** *user's location is meeting room* ***AND*** *user's current schedule is meeting* ***THEN*** *divert incoming call to the user's message box*. The policies whose conditions satisfy the particular environment

Presented at the 6th International Conference on Intelligent Environments (IE'10), Kuala Lumpur, Malaysia. 19-21st of July 2010


will be activated automatically by a policy decision engine. In this context, the internal logic of an adaptive service is in the form of a family of loosely-coupled policies of no particular order. Then the adaptive service itself is a collection of these policies plus a policy decision engine that reasons over these policies and an action engine that provides the real implementation of these policies. The adaptability of the adaptive service comes from its awareness of the changes of the operation environment, i.e. the context. Anything that is of interest to an adaptive service can be regarded as this adaptive service's context. Service adaptation occurs when there is an interesting change in the context. This context change is reported to the decision engine through an event, and then the decision engine makes a proper decision by reasoning over the policies. The reasoning process might involve in conflict resolution if the new contextual changes result in incompatibility with user or system requirements.

Other aspects of service management such as service deployment, service discovery and service composition are also researched over the test bed using a combined technique of policies and Object Management Group's MDA (Model Driven Architecture). Some scenarios that could run on different types of client devices such as Linux PCs, MS Windows-enable HP PDAs and Android smart phones have been developed. The software toolkit and scenario source code can be downloaded from [4].

## IV. Applications, Services & Scenarios

A number of IP-based services have been applied to the fixed testbed such as: IPTV, video-on-demand, high-definition video conferencing, Voice over IP (VoIP), storage backup and networked gaming. Required end-to-end quality of service is maintained by ensuring adequate network resources are reserved across the core and access network using multi-layer dynamic bandwidth assignment algorithms described in section III. The following section will highlight some of the main applications and scenarios that are currently available and being evaluated/integrated.

### *A. iSpace*

The iSpace provides a flexible test-bed for research into intelligent buildings a phrase that describes living environments that are fitted with network based sensors, actuators and other appliances which can coordinate their actions to offer new types of holistic system behavior which are often labeled "smart" or "intelligent" [5]. The term intelligent is frequently synonymised with other phrases such as smart-home, digital homes, networked homes and intelligent buildings, as all these terms describe systems of interconnected embedded-computers which are capable of local, remote and collective management. In fact, there is almost no limit to the type of environment involved as it could also refer to offices, factories cars airplanes etc, in fact any technology supported environment based around networked embedded devices. What makes these environments intelligent is the use of intelligent-agents to orchestrate this holistic networked behavior [6]. In terms of domestic homes, the roots of building automation can be traced to PICO, a small Scottish company, who, in 1975, started the X10 project a power line network standard enables a computer, with suitable software, to control electrical power outlets by propagating signals along the power line. Home automation standards are essentially descriptions of network transport mechanisms and communication protocols. More recently numerous newer and better standards have appeared such as LonTalk, BatiBus, CEbus, EIB, EHS, HBS etc. These specialized network standards are fighting for dominance of the intelligent buildings market, along with the already dominant Internet protocols. The advent of home broadband has given IP an edge in the smart-home market where the synergy arising from using existing home gateways and set-top boxes provides commercial advantages to all concerned. Examples of projects that have been undertaken in the iSpace range from the investigation of virtual appliances built from aggregations of network services, the use of networked embedded-agents to make energy efficient home [7], follow-me and mixed reality entertainment, plus medical and care applications [8].

### *B. Fixed Mobile Convergence*

Future mobile devices will have even more wireless interfaces and the advent of long-term evolution (LTE) mobile technology will offer unprecedented broadband capability; this will have a dramatic impact on the fixed backhaul networks of mobile operators. In order to experimentally evaluate and validate modeled mechanisms and algorithms for QoS-aware mobile handover and dynamic bandwidth allocation for mobile backhaul networks, the configuration shown in figure 10 has been constructed. The dotted line is the path that a pedestrian may take when walking from a car park to the main campus of the university following the walkway.

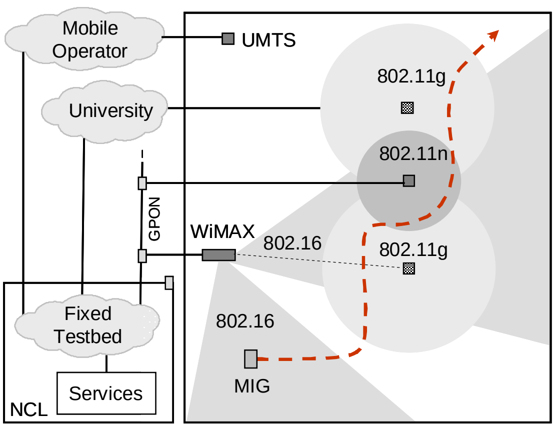


**Figure 10: Fixed/mobile convergence testbed**

The path offers a variety of wireless access points to which the user's mobile device can connect ranging from Universal Mobile Telecommunications System (UMTS), 802.11g (54Mbit/s) Wi-Fi via the University campus network, 802.11g Wi-Fi via a WiMAX and GPON backhaul or a high-speed 802.11n (300Mbit/s) Wi-Fi backhauled via the GPON.

The state of each of the access points is monitored and handover decisions are based on the current AP state and pre-defined policies. In order to evaluate different policies, real users are emulated using wireless traffic generators located near the access points in order to load and change the AP performance (excluding the UMTS network). The GPON backhaul bandwidth assigned to each access point is dynamically adjusted for each of the classes of services to ensure adequate end-to-end quality of service. This is done prior to a handover initiation.

In order to evaluate advanced tele-health applications, a media independent gateway (MIG) has been constructed and used in e-health applications in order to maintain an "always-on" connection for real-time monitoring of vital statistics measured by Bluetooth-enabled sensors. The MIG is equipped with a GPS receiver for positional information and three different wireless interfaces (WiMAX, WiFi and UMTS) as shown in figure 11.

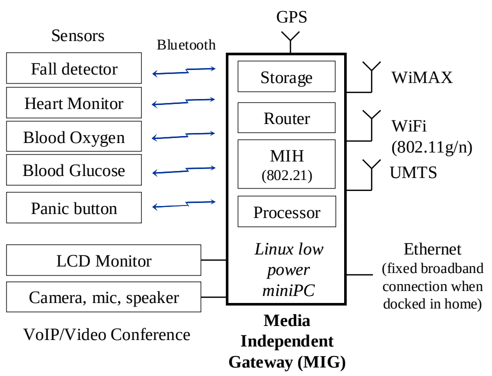


**Figure 11: Media Independent Gateway for e-health applications and QoS-aware mobile handover**

The router provides the IP-routing capabilities and the standardized media independent handover (MIH) protocol ensures handover whilst roaming [9]. Local storage is necessary in case of complete network outage. Both VoIP and video conferencing is also possible, but more plausible when the unit is used as a home hub and a fixed Ethernet connection attached.

### *C. Location-based services*

Although the iSpace offers location detection with an accuracy of 2cm, a location-based system that utilizes the existing Wi-Fi network infrastructure is being integrated into the testbed across the campus. This will offer location accuracy to within 2m and complement the existing GPS-based system used in the MIG as described in part B. Once installed, a number of location-aware services will be enabled. The first of these services will be an interactive way-finding system that offers a layered mapping service primarily designed for disabled access across campus. The system has been developed to guide a user given certain physical capabilities (eg for a wheelchair user, the user can select to find a path without a gradient or without stairs). A digitized version of the campus routes and their attributes (eg gradient, stairs, distance etc) has been entered into an SQL database and a constraint-based shortest path routing algorithm determines the optimum route. Many offices and lecture rooms are difficult to find and presently the user is guided to the correct entrance and floor level. Further information about the destination is also available (eg opening and closing times of the library, food available at a restaurant, taxi telephone numbers, bus times etc).

## V. Discussion & Future plans

Future work will include the addition of location-based services, dynamic content caching and the extensions of the testbed to Southend. Currently, parts of the network infrastructure are being adapted for use within an assisted living project, PAL [10] that will use health applications to evaluate a new information-centric routing paradigm as a possible "clean-slate" Internet architecture. Extensions to health and care-home institutions are being considered in order to include another type of user base within the testbed.

## Acknowledgment

The authors of this paper would like to acknowledge Engineering and Physical Science Research Council (EPSRC) and Technology Strategy Board (TSB) for funding the PAL and HIPNet projects.

## References

[1] http://www.ja.net/
[2] http://gow.epsrc.ac.uk/ViewGrant.aspx?GrantRef=EP/E002382/1
[3] R Martin and K Guild "An Efficient Algorithm for Dynamic Bandwidth Allocation" International ICST Conference on Broadband Communications, Networks & Systems: BROADNETS 2009
[4]http://privatewww.essex.ac.uk/~kunyang/Projects/EPSRC/PANDA-software.html
[5] J.C. Augusto (2009) Past, Present and Future of Ambient Intelligence and Smart Environments, In "Agents and Artificial Intelligence, Communications in Computer and Information Science, Vol. 67. ISBN: 978-3-642-11818-0. Springer Verlag.
[6]Chin J, Callaghan V and Clarke G, "Soft-appliances: A vision for user created networked appliances in digital homes", Journal of Ambient Intelligence and Smart Environments (JAISE) Volume 1, Number 1 / 2009, pp 69-75, ISSN 1876-1364, IOS Press
[7]Callaghan V, Woods J, Fitz S, Dennis T, Hagras H, Colley M, Henning I, "The Essex iDorm: A Testbed for Exploring Intelligent Energy Usage Technologies in the Home", Proceeding of the 3rd International Conference on Intelligent Green and Energy Efficient Building & New Technologies, International Convention Centre, Beijing China, 26th-28th March 2007
[8]D. Pavel, V. Callaghan, A. Dey, "Democratization of healthcare through self-monitoring technologies". Pervasive Health 2010 conference, Munich, Germany, March 2010
[9] http://www.ieee802.org/21/
[10] http://www.palproject.org.uk/