Y-Comm: A Global Architecture for Heterogeneous Networking
Invited Paper

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ABSTRACT
In the near future mobile devices with several interfaces will become commonplace. Most of the peripheral networks using the Internet will therefore employ wireless technology. To provide support for these devices, this paper proposes a new framework which encompasses the functions of both peripheral and core networks.The framework is called Y-Comm and is defined in a layered manner like the OSI model.
Keywords: Heterogeneous Networking, Mobility, Architectural Framework.

1. INTRODUCTION
Mobile devices with several wireless interfaces will soon become readily available to consumers. We define the networking issues associated with this type of device as **heterogeneous networking** and the devices themselves as **hetnet** devices. Users of hetnet devices will expect these devices to provide global access, seamlessly switching between available networks.

This is a very demanding task which must be achieved taking into account the current networking context. Key observations include: firstly, the expansion of the number of wireless networks at the physical and link levels is contrasted with the convergence on the use of the Internet Protocol (IP) at the network level to build global multi-service networks. So a fan-out at the lower level is being met by a fan-in at the network level, making the integration of these wireless systems a serious challenge. Secondly heterogeneous networking also involves support for vertical handover in which connections operating over one network can be seamlessly switched to another network.

One of the key issues of vertical handover is the need for systems to support Quality-of-Service (QoS) because the properties of individual links and networks may vary considerably. This will in turn affect how well network and transport services can deliver effective services to applications. For several reasons, traditional frameworks such as the OSI Model [20] are proving ineffectual. Firstly features, such as vertical handover, which are essential for heterogeneous networking, cannot be easy modelled using the OSI model. Secondly, we are witnessing a radical change in the recent network evolution of the Internet. When the Internet was young, the peripheral networks were primarily Ethernet and Token Bus systems which were similar in terms of performance and technology with the systems used in the core network. However recently there has been a radical divergence. The core network is actually getting faster in terms bandwidth as well as latency with the use of single-mode optics and Multiple Label Switching (MPLS) technologies. In contrast, new peripheral networks are being predominantly built using wireless technologies including WLAN, Bluetooth and WiMax systems. The characteristics of these systems are totally different in terms of latency and bandwidth as well as error distribution properties compared with those in the core network.

A major observation about this development is the weakening of the end-to-end arguments which has been a key part of the design framework for the development on the early Internet. We believe that this means that we need to think of the Internet as a global network which should be divided into two key components. The first is the Peripheral Network and the second would be the Core Network which also includes access networks. This highlights the

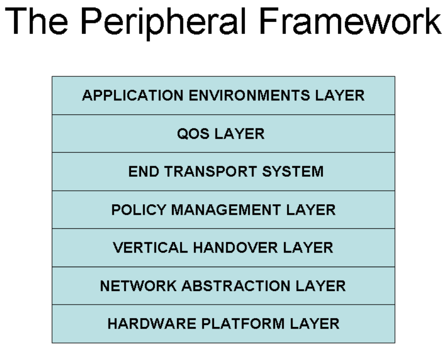

Figure 1: The Peripheral Framework

fact that the challenges in the Peripheral Network will be different from those in the Core Network and so it will be necessary to consider developing an architecture with not just one but two major frameworks.

In August 2006, a framework covering the Peripheral Network [13] was presented. In this paper, we begin by defining an architectural framework for the Core Network, which compliments the Peripheral Framework. We then combine the two frameworks to specify a complete telecommunications environment. The rest of the paper is presented as follows: Section 2 looks at the Peripheral Framework while Section 3 describes the required functionality needed in the core network to support the Peripheral Framework. Section 4 explores the layers of the Core Network and Section 5 combines both frameworks to form the Y-Comm architecture. Section 6 looks at previous and current work being done in this area of research while Section 7 looks at future work. The paper concludes with a summary and conclusions in Section 8.

2. THE PERIPHERAL FRAMEWORK

Figure 1 shows the Peripheral Framework developed for Heterogeneous Networking. For clarity of argument, a brief summary is now given; a more detailed explanation of the architecture is found in [13].

- Layer 1: **The hardware platform layer**: this layer is used to define the hardware components and technologies required to support a particular wireless network, including electromagnetic spectrum, modulation techniques, Media Access Control (MAC) algorithms, etc.

- Layer 2: **The network abstraction layer**: this layer specifies a common networking interface which all networks employing this architecture must support. This interface is used to maintain and control the network on the mobile node.

- Layer 3: **The vertical handover layer**: this layer is concerned with the specification of mechanisms including state engines and triggers for vertical handover. There are two kinds of vertical handovers. The first is network-controlled and is managed and maintained in the core network. The second is client-controlled in which the client controls handover.

- Layer 4: **The policy management layer** : this layer is used to evaluate all the circumstances when handover should occur. The layer can be implemented by defining certain rules with regard to all the relevant parameters and their values which are evaluated with respect to handover.

- Layer 5: **The End Transport System**: this layer looks at moving data to and from the mobile node. Alternatives to TCP/IP should be sort so as to get better performance when transporting data in heterogeneous wireless networks.

- Layer 6: **The Quality-of-Service (QoS) Layer**: this layer helps to ensure that quality-of-service required by applications can be maintained as the quality-of-service being offered by the network is dynamically changing as the mobile node moves around.

- Layer 7: **The Application Environments Layer** specifies mechanisms and routines that allow applications to be built which can use all the layers of the framework.

3. IMPLICATIONS FOR THE CORE NETWORK BASED ON THE PERIPHERAL FRAMEWORK

Some key observations about the Peripheral Framework: firstly, the Peripheral Framework is designed to be implemented on hetnet devices. The vertical handover layer supports both network-based and client-based handovers. However, we believe that client-based handover offers many advantages over network-based handover for heterogeneous networking [15]. Vertical handovers require complete knowledge of the state of wireless networks to which the mobile node is attached. We believe such information would be more readily available from the interfaces on the mobile node. It is also very difficult to see network operators making their network status available to their competitors. Secondly, it should be also recognized that the state of the higher levels of the protocol stack such as the state of the TCP connections on the mobile node does need to be taken into account to assure seamless handover. However, in order for client-based handovers to work, the mobile node would need access to network resources in order to facilitate vertical handover. This must therefore be a key requirement of the Core Framework.

Secondly the Policy Management System is meant to support proactive policies which attempt to determine the network characteristics at a given location before the mobile device actually reaches the location. This can be done using a knowledge-based system in which the parameters at that location have been previously measured. The other approach is the use of a simple mathematical model based on the distance of the mobile node from nearby based stations as well as the direction and velocity of the mobile device. Proactive policies attempt to determine the Time Before Vertical Handover (TBVH) which can be used to minimize packet loss and latency during handover. In order to calculate TBVH, the policy management layer would need to know something of the network topology and the performance of the relevant base-stations. A major new nomenclature is the concept of a Boundary Base Station (BBS) which is a base station on the boundary of the network. A BBS is the last base station that must be traversed just before vertical handover. So it is important for different networks to be able to describe their network topology in a way that facilitates the calculation of TBVH.

Thirdly the End Transport System looks at network and transport protocols in the peripheral network. The authors have shown that there have been problems with the use of TCP/IP in wireless networks. We believe that the search for alternative protocols which would work better over wireless systems should be pursued. However, the core network should continue to run TCP/IP so there will be a need to switch from the protocols running in the peripheral network to TCP/IP and back again to allow hetnet devices to communicate with each other.

Finally, though, there will be a weakening of the end-to-end transport mechanisms, successful communication does demand end-to-end QoS support. It will therefore be necessary to map the QoS available in the peripheral networks to the QoS in the core network and vice-versa.

3.0.1 *Networking Issues for the Core Network*

There are additional issues which need to be considered. It would be beneficial if the Core Framework attempted to address key issues in the management of large telecommunication systems. Firstly, network operators presently dominate telecommunication systems resulting in a highly vertical architecture. The new framework should attempt to define an architecture that allows a more horizontal approach. In this regard, it is felt that a tightly layered approach in which the functionality of the layers and the interfaces between them are clearly defined. This will allow entrepreneurs to specialize in providing particular services.

Secondly, there is also a requirement to be able to define and manage non-overlapping networks on a single hardware platform. Such a design would allow the development of city-wide or regional wireless networks which can be better tailored for relevant users. This would also allow the deployment of new technologies in a limited geographical environment making a more viable business by gradual deployment of services. Presently, large scale national networks such as 3G must be deployed at a national level. This requires a lot of expense and thus can only be done by companies with deep pockets. A major feature of the framework is the need to support network virtualization and partitioning which can be used to define a virtual network which is managed by a network operator and can be viewed by a subset of an extensive hardware platform.

Finally, we believe that in order to enhance the new architecture, it is necessary to provide support global service platforms. These platforms would allow services to be implemented and managed independently of any network. Currently, this is not possible as the deployment of a given service must be done on each individual network.

4. THE CORE FRAMEWORK

The Core Framework is shown in Figure 2. The first two levels of the Core Framework are similar in purpose to the first two layers of the Peripheral Framework, but while the Peripheral Framework specifies software such as device-drivers in order to support a given network on a mobile node, in the Core Framework these layers represent the specification and software needed to run in the base station of a given technology. The relationship of these layers in the two frameworks is analogous to the specification of the modem (DCE) and terminal (DTE) definitions found in wired data communications; however in this case we look at specification from a wireless and not a wired context. So the base-station specification corresponds to the DCE while the mobile node is analogous to the DTE end of the interface.

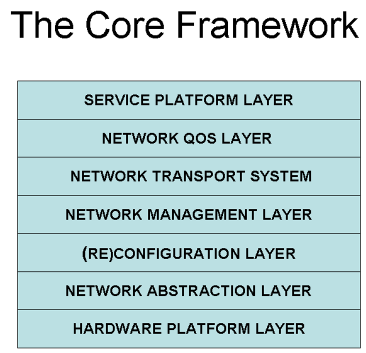

Figure 2: The Core Framework

The **(Re)configurable Network Layer**: this layer is used to configure networking resources in the core network. This would include various network switching elements such as mobile switching centres, gateway GPRS support nodes and routers [10]. This interface will also be used by the Vertical Handover layer in the Peripheral Framework to obtain network resources for a vertical handover before it occurs. Network events as well as the configuration of new resources to satisfy the QoS requirements may generate new reconfiguration needs in order to guarantee the stability of the whole system. Reconfigurable systems benefit greatly from the virtualization of hardware components such that it is possible to have a small number of virtual units, for example, switchlets [6] or routelets. Though it is clear that a lot of research has been done in this area and some of it has found its way into commercial products, what is missing is the opening up of these interfaces [1] to hetnet devices. The drive to open up these systems have not gone far enough and without this it will not be possible to build networks that are different in scope and functionality using the same hardware. This ability is necessary for the next stage in network evolution [12]. Of course such an effort must be accompanied by the required security framework to prevent hetnet devices trying to abuse the use of core networking resources.

The **Network Management Layer**: This layer is highly significant as it acts as a control plane that uses the programmable network layer to bring together various hardware and software components to build enterprise class networks. Each network will have an operator that controls it. To do this, the layer must also provide authentication, access control, accounting and charging (AAAC) systems [16]. It must also support the use of policy mechanisms to allow operators to dictate which hardware components may be used on their networks. The Policy Management Layer in the Peripheral Framework can interact with the Network Management Layer in the Core Framework to help inform mobile nodes about network resources to which it could have access on specific networks. The Policy Management layer uses this information to tell the Vertical Handover layer on the mobile device about which network resources can be obtained for a vertical handover. Since both the Network Management Layer and the Policy Management layer have their own policies to follow, a conflict resolution process should be carried out between them.

The **Core Transport System**: This layer is about network addressing and transport mechanisms in the core network. Currently TCP/IP is used in the core network and we are of the opinion that it should continue to be used, though a move to IPv6 is necessary to add enhanced network capabilities and integrate the various value-added technologies into one core protocol.

The **Network QoS Layer**: This layer is responsible for QoS issues within the core network. It looks at how QoS may be defined and the mechanisms used to establish and maintain QoS at different points in the system [7]. With the failure of IntServ [2] and the slow deployment of DiffServ [8], a new model for handling QoS issues is required. A lot of motivation for the development of IntServ and DiffServ was the belief that the Internet would soon be unable to deal with the huge increase in traffic that would be spawned from its high growth rate [9]. However what has happened is that the core network has become faster, minimising the threat of congestion in the core network. In addition, the development of heterogeneous wireless networks means that there are more severe QoS issues in the peripheral network than in the core network. We therefore believe that QoS issues in the core network should be approached from the network level rather than from the application or device level. Hence, a novel approach is to develop a QoS architecture based on the ability of peripheral networks, rather than individual machines, to calculate and specify their QoS requirements. These networks will then negotiate with the core network to obtain the required resources to meet their QoS needs.

The **Service Platform**: The Service Platform allows different agents to install and operate various services in a secure and controlled fashion. The service platform will provide the ability to install services in component form on several networks simultaneously, or on a single network. This will therefore allow the provision of both national and regional services to be easily constructed, e.g. traffic information in London would be a local service accessible to networks operating in London. There is enormous scope for such location-based services.

5. THE Y-COMM FRAMEWORK

In this section, we attempt to put the Peripheral Framework and the Core Framework together to represent a future telecommunications environment which supports heterogeneous devices, disparate networking technologies, network operators and service providers. This is shown in Figure 3.

The two frameworks share a common base subsystem consisting of the hardware platform and network abstraction layers. Both frameworks diverge in terms of functionality but the corresponding layers interact to provide support for heterogeneous environments.

6. PREVIOUS AND CURRENT WORK

With regard to the Peripheral Framework, a lot of recent research in mobile networks has looked the vertical handover. This was also explored by the development of the Cambridge Wireless Testbed [3] which was built by the Computer Laboratory, University of Cambridge. The testbed was unique as it explored vertical handover in LAN, WLAN and 3G networks. It pioneered the use of client-based handover techniques [14]. In addition, the Cambridge testbed was used to look at reactive mechanisms for policy management called PROTON [19]. This was implemented as a three-layer subsystem. The lowest level was the hardware execution layer, which performed the actual handover. The second layer was the policy layer which allowed policies to be specified as rules which were used to decide whether handover should be initiated. The final layer was an input/output layer which fed events and triggers into the policy layer.

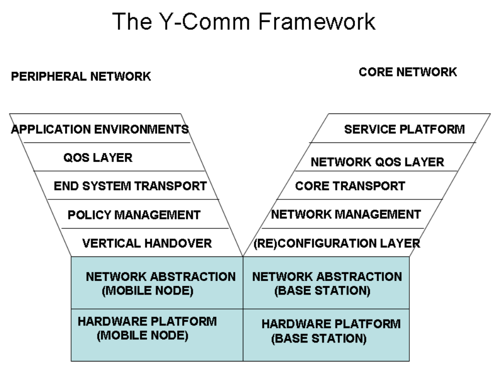

Figure 3: The Y-Comm Framework

The efforts detailed above concentrated on the layers 3 and 4 of the Peripheral Framework. Work is also looking at defining the lower layers of this framework. Recently, the IEEE convened the the **802.21** [1] Working Group to examine the possibility of standardising the interface to different wireless MACs. In our view, this work can be used as a prototype of the mobile-node side of the network abstraction layer.

Recent work has been looking at developing proactive management policies. At the University of Cambridge coverage maps for WLAN, GPRS and 3G networks throughout the city are being developed [4]. This will allow hetnet devices to ascertain coverage at a particular location. A proactive system based mathematical modelling is being pursued by the Networking Research Group at Middlesex University [18]. The aim is to find a simple and efficient way of calculating the Time Before Handover (TBVH). Analytical models have been developed and are being verified using simulations in OPNET. A prototype model for providing support for QoS is also being developed [17]. Finally, work has also begun to look at Network and Transport protocols for the End Transport System using the Plutarch Model [5].

In terms of the Core Framework, work has begun to look at the Reconfiguration Layer. There has been a careful review of the Programmable and Active Network Research that was done in the late 1990s [11]. The idea is to use this work as a starting point to define a layer that can allow mobile nodes to acquire the necessary resources to aid client-based handovers. We are also beginning to look at extending the work being done by the IEEE 802.21 Working Group to cover base-station functionality.

7. FUTURE WORK

There is a proposal to extend the Cambridge Wireless Testbed to cover a 4 square-km area in the West of Cambridge. This will allow the development of the higher layers of the Peripheral Frameworks as well as levels 3, 4 and 5 of the Core Framework. We would like to look at network management, in particular, network virtualization and partitioning techniques. This would allow us to

[1] http://www.ieee802.org/21/

define and manage new networks based on an extended hardware platform. After this, we would like to look at layers 6 and 7 of the Core Framework.

We recognize there are tremendous challenges in trying to prototype the Y-Comm Framework and therefore appeal to the networking research community to engage seriously with this effort.

8. CONCLUSIONS

This paper has proposed a new architectural framework for Core Network Infrastructure to support Heterogeneous Networking. We have combined this framework with the previously defined Peripheral Framework to form the Y-Comm architecture which we believe can be used to build future telecommunication networks for heterogeneous networking. The authors would welcome feedback on the contents of this paper.

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