End-to-end QoS Control for an ALL-IP (NGN) Platform using WiMax as an Access Layer Network

Bessie Malila, Neco Ventura
University of Cape Town, Depart of Electrical Engineering
Rondebosch Cape Town 7700
Tel: +27 21 6502813
Email: {bmalila, neco}@crg.ee.uct.ac.za

Abstract-**Telecommunications networks are evolving towards an integrated ALL-IP architecture, commonly known as the Next Generation Network (NGN). The architecture consists of Broadband transport technologies both on the access and core networks. One of the problems in NGN architecture is the ability to guarantee end-to-end Quality of Service (QoS) provisioning to the integrated network services in the form of voice, video, data, fax and IPTV. These services present complex QoS requirements on the transport networks. In this paper we present an integration of the main components of a NGN on a test bed. We build an IP core network based on Linux routers and integrate it with an existing WiMax access network, an existing IP Multimedia Subsystem (IMS) network as the control layer component and a content server as an application layer entity. We further propose a mapping of QoS classes between the two networks to achieve end-to-end QoS guarantees. This project builds on previous and current research work in the Communications Research Group at the University of Cape Town. Link test have been used to check the link connectivity and link quality on the network. Future work will involve enabling QoS on the IP network so that the network is able to carry multimedia applications and implementation of the QoS mapping strategy between the two network domains.**

Index Terms—DiffServ, NGN, QoS, WiMax

I. INTRODUCTION

Next Generation Network (NGN) refers to a packet-based All-IP network which is able to make use of multiple broadband, QoS-enabled transport technologies [1]. The architecture NGN is a four-layered hierarchical structure comprising independent access, core, control and application layer networks. Interworking units and gateways interconnect the different networks. The architecture is horizontally integrated, making it possible for users to access networks of competing service providers and/or services of their choice. In the NGN service-related functions are independent of underlying transport-related functions. It will therefore be possible to enable services without considering the underlying transport technology. The network will support generalized mobility which allows consistent ubiquitous provision of services to users. The architecture will also enable voice, video, fax, data and

other multimedia applications to run on the same transport plane. Applications like voice and video will be independent of the access network and will reside on end-user devices. The NGN is based on standard signaling protocols. There are two competing signaling protocols to date, the Session Initiation Protocol (SIP) and H.323, although the H.323 is more suitable for fiber optic cable backbone networks and SIP for "local loop". However SIP is more likely to be adopted because of its use in the IP Multimedia System (IMS) [2].

The underlying technologies for the core transport networks are the Internet Protocol (IP) and Multiprotocol label Switching (MPLS), which evolving towards the Generalized MPLS (GMPLS). The underlying technologies for the control layer are the Softswitch, a programmable device for controlling voice over IP calls (VoIP) and the (IMS). The application layer will be made up of content servers which make use of the capabilities provided by the other functional planes to provide multimedia services. A management plane, capable of interacting with all the networks will provide a platform for the management of such functionalities as quality of services (QoS), network security and network configuration. The access layer will be made up of heterogeneous network technologies capable of providing seamless roaming to subscribers across the different networks. Technologies on the access layer include Wireless Interoperability Microwave Access (WiMax), Digital Subscriber Line (DSL), Wireless Local Area Network (WLAN), Code Division Multiple Access (CDMA) and the Universal Mobile Telecommunications System (UMTS) which is evolving to the Long Term Evolution technology (LTE) [3]. The NGN access networks must be able to provide the best QoS, least cost, widest coverage and highest security. User devices must have least power consumption. Users must be "always best connected".

The independence of the layers as well as the fact that all networks are IP-based will allow network operators to integrate the best technologies at each layer at the minimum cost. Operators need not be locked to one equipment supplier from access up to application layer, as was the case before in legacy networks. This ability to integrated different technologies has ignited intense competition among manufacturers of component layer networks, resulting in high quality networking products. The development of such technologies as the WiMax and the 802.11g WLAN products capable of providing QoS enabled broadband wireless access networks has made mobile network operators rethink their business strategies. The traditional Telco operators are nolonger able to lock customers to their networks. A glaring example is the

emergence of VoIP services and other peer-to-peer applications on the Internet which caught network operators by surprise when they realized that they were losing substantial revenues especially on international calls as subscribers preferred to "Skype" or "Google talk" at the cost of a local call using the very same network resources, if not more! The ever increasing capabilities of end user terminals also provide more choices to the subscribers.

The NGN is based on open standards and as such different networks based on different technologies are supposed to be interconnected and provide services seamlessly across the networks. While a lot of research has been going on which has resulted in the evolution of wireless networks to WiMax and LTE technologies, interworking these technologies with core, control and application services networks based on different technologies without losing the benefits realized, is a big challenge to many network operators. MPLS on its own is an excellent technology which addresses traffic engineering problems on core networks. MPLS-based network nodes, however can only translate the traffic handling techniques to another node only if it MPLS enabled, making it difficult for network operators to integrate the technology with existing IP based nodes. Network integration therefore remains problematic for many network operators.

In this paper we present an integration of real NGN networks as recommended by the International Telecommunication Union-Telecommunications Standardization Sector (ITU-T) [4] into a unified NGN platform. The implementation is a result of ongoing research within the Communications Research Group (CRG) at the University of Cape Town. Our work involves the installation of a WiMax access network working in Point-to-Multipoint mode with three Subscriber Stations and a core network based on Linux routers. The control layer makes use of the UCTIMS client [5]. The WiMax network is based on the Alvarion Fixed Wireless Access solution which meets IEEE802.16 as well as WiMax Forum specifications. The application services layer network is based on application servers developed in the CRG laboratory. The resultant platform is a NGN which can be used for further research activities in the still open areas of applications development, network security and QoS. Fig. 1 shows an overview of the network architecture.

While the IPTV server has been implemented, the Advertising server is still under development and is expected to be functional by December 2009.

APPLICATIONS/SERVICES — IPTV, VIDEO, ADVERTISING
CONTROL LAYER — UCTIMS, Internet
CORE LAYER — IP-Core Network, G/MPLS Core Network
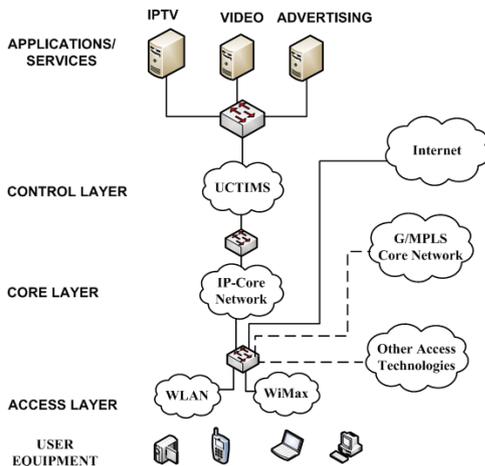ACCESS LAYER — WLAN, WiMax, Other Access Technologies
USER EQUIPMENT

Fig. 1. NGN Integrated architecture

The video server hosts a number of video applications which are used for generating video streaming traffic.

Our aim is to build a QoS-enabled network based on the NGN architecture. The access network is based on the Alvarion's WiMax Point-to-Multipoint broadband WiMax Fixed Wireless Access solution. The network has in-built QoS mechanism capable of handling multimedia applications. The core is built using Linux routers. The default QoS capabilities on the core network cannot handle multimedia applications with varying delay and jitter requirements. Such algorithms as Generalized Random Early Detection (GRED) must be implemented to enable this capability. The University Of Cape Town (UCT) Communications Research Group has been actively involved in the development of an IMS client, NGN applications and wireless access networks. In this paper we present how the different network components have been integrated into a unified NGN platform which can be used for further research in NGN technologies.

With the platform in place, the first area of focus has been end-to-end QoS provisioning on the network. Both the access and core networks must be QoS enabled. End-to-end QoS provisioning is achieved through mapping QoS classes of the access and core networks using the DiffServ model as the common model between the two networks. We also propose that traffic from the wireless network be treated better than Best Effort traffic in the core network so that it does not compete with traffic from wired access networks. In the next section we discuss some of the activities in the standardization sectors and other research institutions related to QoS for the NGN.

II. QOS IN IP-BASED NETWORKS

Packet-based networks, from which the NGN evolved, are prone to delay, jitter and packet loss. Initially this was of no concern since the traditional internet traffic - email, web-browsing and data traffic - is not affected by these parameters and besides. The Internet was designed to deliver best effort QoS. The advent of multimedia applications like video, IPTV, online gaming and VoIP services has resulted in the need by network operators to the problem of end-to-end QoS control. Successful implementation of the NGN will require that these problems be addressed. Managing end-to-end QoS in NGN networks is made more complex by the heterogeneity of the technologies integrated on the architectures.

The ITU-T stresses that QoS provisioning on NGN must take into account application QoS requirements, user quality of experience QoE [6] and availability of network resources. In an effort to address end-to-end QoS provisioning for NGN traffic, the ITU-T has defined some frameworks [7], [8] as guidelines for network operators and equipment manufacturers for end-to-end QoS implementation.

In addressing QoS in IP networks, four key parameters need to be addressed - delay, jitter, packet loss and available bandwidth. Delay on networks is due to router processing, queuing of packets in the routers while waiting to be processed, transmission time and propagation on the network. Network congestion also contributes to network delay. Jitter is the variation in delay. A large jitter value has a negative impact on VoIP and video applications. Packet loss can be a result of network congestion or a break in the

communications link. The problem of bandwidth has been addressed by solutions such as over provisioning, use of fiber optic cable and use of advanced technologies such as multi-input-multi-output (MIMO) on the air interface for wireless networks.

The Internet Engineering Task Force (IETF) has defined a number of mechanisms for addressing QoS control on IP networks. First to be defined was the Integrated Services (IntServ) architecture/ Resource Reservation Protocol (RSVP) [9]. This was superseded by the Differentiated Services (DiffServ) [10] architecture which addressed the scalability issues of the IntServ model. The IETF is currently developing the Next Steps In Signaling (NSIS) protocol, a bidirectional signaling mechanism to address the inability of DiffServ to provide end to end resource reservation. The Weird Project [21] implemented a solution in which NSIS protocol was used for end to end signaling and DiffServ for traffic classification and conditioning using WiMax as an access network.

III. RELATED WORK

To address the problem of end-to-end QoS provisioning, the 3GPP recommends mapping the four QoS classes of the UMTS technology to DiffServ Code Points (DSCP) [12] to an enable translation of QoS parameters from the network to peer IP networks using the DiffServ QoS model. The MPLS core transport technology also provides for translation of QoS classes defined in MPLS-based nodes into the DiffServ QoS model [13]. The IEEE802.16 standard also recommends translation of QoS classes to the DiffServ QoS model by assigning DiffServ Code Points (DSCP) to service flows which have been assigned one of the five QoS classes. The standard does not however specify how this can be done.

The above solutions make use of QoS implementations in the individual technologies without addressing the requirements of end users whose applications must traverse different networks and/or different operator domains. Another dimension from which the problem is being addressed is the use of policy-based QoS mechanisms. Various standardization bodies are working towards a generalized framework for policy-based admission control and end to end QOS control for NGN networks [14]. The IMS [15], also under development within the 3G Partnership Project (3GPP) is also designed to provide among other services, QoS control for NGN applications. These solutions have drawbacks of requiring some changes within existing network nodes. They are most suitable for upcoming network operators, in developing countries, whose networks are still under development and are based on the latest access and transport technologies.

Other implementations include the use of a Band width Broker (BB) [16] and Overlay Networks [17]. Both the BB and overlay networks do not require changes in the existing network infrastructure, making them more attractive to network operators. The BB and overlay networks however just monitor networks and route traffic to congestion free networks, without addressing the QoS control in network nodes. Multiprotocol Label Switching (MLPS) has been adopted as a NGN core transport technology because of its ability to provide QoS provisioning.

IV. DIFFSERV AND WIMAX QOS MODELS

The NGN is an All-IP platform. The DiffServ QoS model has been widely implemented on IP-based networks. As a result QoS –enabled transport technologies provide for QoS translation from their QoS classes to the DiffServ QoS classes. This enables QoS translation from one network domain to the other. Most of the transport technologies have DiffServ QoS mechanism installed as modules to enable QoS translation to other IP-based networks.

WiMax is a Broadband wireless technology promising to deliver the NGN applications better than existing wireless technologies. WiMax has a robust QoS mechanism which allows network operators to map QoS parameters from the defined QoS classes to DiffServ Code Points (DSCP) which can be used as the basis for traffic classification in the next domain. Its ability to provide QoS has resulted in it being widely adopted as a broadband fixed wireless access technology. The 802.16e standard adds mobility to the standard. Our work is limited to the fixed wireless access standard, although the concept can applied the mobile standard since the two standards only differ in the subscriber mobility of the user equipment in the 802.16 standard.

A. The Differentiated Services QoS Model

The Differentiated Services (DiffServ), quality of service model [18], [19], [20] superseded the Integrated Services (IntServ) quality of service model which could not scale as the number of internet networks increased. The DiffServ model addresses this by grouping IP packets with the same QoS requirements and classifying the traffic into several QoS classes.

Traffic on a DiffServ network can be classified into three broad categories called Per Hop Behaviors (PHB): Expedited Forwarding (EF) – for low latency, low loss traffic like voice or video, Assured Forwarding (AF) – for traffic that may not be sensitive to delay and jitter but may require special treatment in terms of throughput and low packet loss. This is further subdivided into four classes with each class being able to provided three levels of drop precedence to traffic within that class, therefore providing the capability to handle traffic according to QoS requirements and specifications. The Best Effort (BE) class is for best effort delivery of the traditional internet traffic. Traffic in each PHB receives the same forwarding treatment on a router.

One of the advantages of the DiffServ model is that it is relatively easier to implement. In the model all traffic classification and policing is done at the edge node leaving core network elements to forward packets. Service Level Agreements (SLA's) and charging issues are also moved to the edge node. Another advantage is that DiffServ requires no advance set up, resource reservation or end to end negotiation for each traffic flow. The DiffServ model has a number of drawbacks. For network operators, one operator may not be able provide the same guarantees to the other operator's traffic. End to end QoS is only guaranteed if peering boundary hosts honor the agreed policies of the peer domain. The Bandwidth Broker (BB) defined by the IETF RFC 2638 attempts to address this problem, in the context of the DiffServ Framework. The DS model works by

deciding which packets to delay or drop in the event of network congestion. In the event of high congestion, some traffic class can be taken out of service completely, although this can be avoided by setting a minimum bandwidth for the lower class traffic. Network operators have also been addressing this problem by using fiber optic cable to provide "fat pipes" between core routers, this is also called over-provisioning. In this case the limiting factor would be the router's processing power and the cost of the media converters. Packet dropping has also been addressed by use of mechanisms like Random Early Detection (RED) and its variants.

B. The IEEE802.16 QoS Mechanism

The IEEE802.16 commonly referred to as WiMax, is a broadband wireless standard that defines the requirements for a wireless network capable of delivering traffic requiring low delay, low jitter, low packet loss and high bandwidth, which are the key requirements for NGN applications such as voice, video and data. QoS on the 802.16 standard is defined both on the physical and MAC layers.

To address QoS provisioning on the physical layer, the 802.16 standard uses adaptive modulation, Orthogonal Frequency Division Multiplexing (OFDM), Frequency Division Duplex (FDD) and Time Division Duplex TDD), Fast Fourier Transform (FFT) as well as Forward Error Correction (FEC). The MAC layer is connection oriented and allows for service flow classification into four distinct classes of service: Unsolicited Grant Service (UGS), real-time polling service (rt-PS), non-real time polling service (nrt-PS) and best effort (BE). To address end to end QoS provisioning, the WiMax forum states that the DiffServ QoS model can be used where the technology is interconnected to an IP network but it does not suggest how this is to be achieved. In the next section we discuss the concept of QoS parameter mapping and we present a way of mapping the QoS classes on the WiMax domain to the IP core network using the DSCP as the basis for parameter mapping.

V. DIFFSERV AND WIMAX QOS MODELS

The DiffServ QoS model QoS parameters for IP networks define the QoS requirements of IP packets as they enter and traverse a network domain. In the NGN architecture several access and core transport networks can be interconnected either within the same network operator domain or in different domains. Each access or core transport technology defines its own QoS standard and implementation mechanisms. However, application QoS requirements and specifications must be met on an end-to-end basis. User QoE can only be addressed when the user requirements are met irrespective of the technologies the application transverses.

A. Proposed QoS Mapping for a WiMax access and IP Core Networks

To enable end-to-end QoS provisioning on the implemented test bed, we propose using the DiffServ QoS model to translate QoS classes from the WiMax domain to the IP core network using the ITU-T IP classes of service for traffic classification. We propose that BE traffic on the WiMax network be treated better than BE traffic from wired

networks in the IP core network to minimize retransmissions on the air interface. Table 1 shows the proposed mapping between the DiffServ, IP - as recommended by the ITU-T, the WiMax and the UMTS models. The values for the UMTS classes refer to the IP bits used for traffic classification in MPLS.

Where traffic is entering an IP-based transport network from the UMTS network, BE traffic can also be shifted

TABLE I
PROPERTIES PROPOSED QOS CLASS MAPPING

DiffServ	IP	WiMax	MPLS	UMTS
EF	0,1	UGS	101	Conversation
AF_1	2	rt-PS	001	Streaming
AF_2	3	nRt-PS	010	Interactive
AF3	4	BE	011	BE
AF4	4	-	-	-
BE	5	-	000	-

from the UMTS BE classes to any of the AF classes so that this traffic does not compete for resources with BE traffic from wired networks. The ITU-T REC Y.1541 recommends the mapping of different applications to the IP QoS classes. Using the IP QoS traffic classification and the WiMax QoS traffic classification, we map the two classes on the DiffServ domain so that each traffic flow is in the same DiffServ classes. The same DSCP value is used on both networks. Fig. 2 shows the end to end QoS class handling for the two networks. The traditional email and web browsing traffic classes have been shifted to class 4 and the drop precedence in DiffServ is used to differentiate traffic handling priority of the multimedia applications.

B. Network Implementation and Configuration

Our NGN test bed comprises an Alvarion's WiMax fixed wireless access network comprising a Base Station (BS) and
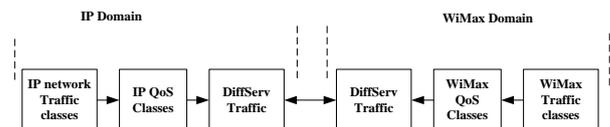

Fig. 2. Proposed end-to-end class of service mapping.

three Subscriber Stations (SS) working in point-to-multipoint and TDD mode. Network configuration and management is done via the proprietary Alvaricraft network management software. Channel conditions are changed by varying attenuation on the RF channel. Service flow classification configurations are carried out on the micro base station using Network Management System (NMS) GUI. The classified service flows are then associated with a DSCP value. The value of the DSCP is used by the ingress node of the transport network for further traffic classification.

The IP transport network is composed of DiffServ-enabled Linux routers. Iptables and traffic control next generation (tcng) software packages are installed on the Linux routers to enable configuration of network security and QoS, although our focus is on QoS implementation. Quagga an open source routing software package [21] is installed on

the routers to provide routing services on the IP network. The software provides dynamic routing capabilities using RIP, BGP and OSPF. In the project RIP is implemented. The package uses the Zebra daemon to manage the routing protocols. This provides a Cisco-like interface for configuring the routers. The Quagga Zebra and RIP daemons are enabled on the routers and the rest of the daemons are disabled.

This set up enables the hosts to interact with the IMS for signalling as well as the application servers for downloading applications. Fig. 3 shows how the NGN network elements have been integrated into a single IP-BASED platform. The IMS provides for QoS signalling [5] between the application servers, and client machines connected to the SS as user equipment. Although the IMS is used for signalling in this case, this is a higher level interaction. The WiMax and IP transport networks provide a path for signalling between the user equipment and application servers. The network does not make use of the QoS capabilities of the IMS to control the network elements on the transport networks. This requires the installation of interworking modules to enable the IMS to control the transport network elements. The details of the signalling mechanism are beyond the scope of this work.
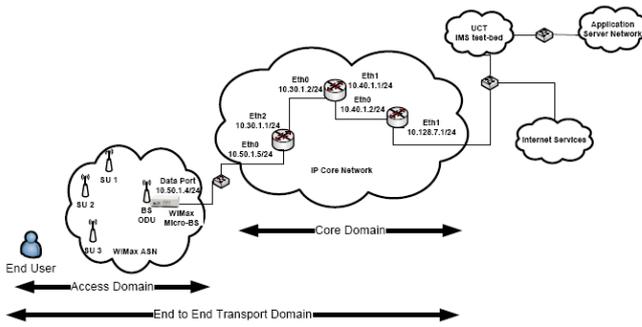

Fig. 3. Proposed end-to-end class of service mapping.
ASN: Access Service
BS: Base Station
SU: Subscriber Unit
UCT: University of Cape Town Network

Video streaming traffic is generated from the content servers on the application layer network. The VLC software was installed on two user machines to enable end to end testing of the network. The Iperf software is used to generate data traffic between two host machines. Network configuration and management for WiMax network is done via the NMS host machine on which the Alvaricraft network management software was installed. The software application only runs on windows machines. Iperf is also used to perform link quality tests used to evaluate the capability of the network to carry video, IPTV, and VoIP traffic simultaneously. Values of jitter, available bandwidth and packet loss are obtained directly from running the application between two hosts. The network segment to be tested is delimited by two hosts running Iperf. Latency is measured using the ping command. Packet loss and jitter are measured with the Iperf UDP test. Bandwidth is measured using Iperf TCP tests.

C. Network Performance Parameters and Measurements

The ITU-T Recommendation Y.1541 provides a guideline of the expected values of delay, jitter, packet loss and bandwidth in NGN networks. These values are used as a basis for evaluating the capability of a network to carry NGN applications before commitments can be made to subscribers or peer networks. Table 2 shows the QoS recommended values for Internet Protocol Television (IPTV), (Voice over Internet Protocol) VoIP and video streaming applications. These values however are for networks spanning distances like US coast to coast. Networks spanning geographical distances less than this are

TABLE 2
QOS VALUES FOR IPTV, VIDEO AND VOIP

Parameter	IPTV	Video Streaming	VoIP
Bandwidth	≥10Mbps	≥2Mbps	64Kbps[1]
Delay	≤100ms	≤400ms	≤150ms
Jitter	≤50ms	≤50ms	≤10ms[2]
Packet loss	≤0.01%	≤0.1%	≤1%

[1]Depends on the codec used.
[2]Not the recommended value by ITU-T but most network operators specify up to this value on their networks

expected to give better values.

Link quality tests are carried out to evaluate the capabilities of the network and hence its ability to simultaneously carry more than one type of traffic as would be required in a practical implementation, for example a SOHO. WiMax network configurations are set to the default optimum performance values. The IP core network is also set to the default QoS parameters set to default Linux traffic handling mechanisms. Performance measurements are carried out in three stages as recommended in the ITU-T REC1541: WiMax segment, the IP segment then end to end segment.

VI. RESULTS AND FUTURE WORK

In this section we discuss the results of the work done and future work.

A. Results

A unified NGN platform is implemented using WiMax as an access technology, Linux routers as IP core network, and uses the IMS as a control layer network. Services for the network are available from content servers on the CRG network.

Ping tests confirm that all the interfaces on the routers were correctly configured. The fact that the hosts can browse the internet indicates that the RIP protocol is running correctly on the routers and packet forwarding is as expected. The NMS is also correctly installed making it possible to manage the BS and the SS. Running a video stream as a base line test application helped in identifying the Avahi daemon which runs on Linux kernels and makes it impossible to run a video stream which requires only 2Mbps on the core network with 96Mbps of bandwidth. After disabling the daemon, the video stream runs without any glitches.

TABLE 3
NETWORK LINK QUALITY TESTS

Parameter	Core	Access Streaming	End-to-end
Throughput	94Mbps	9.65Mbps	9.6Mbps
Delay	0.19ms	31ms	32.3ms
Jitter	0.018ms	2ms	2.03ms
Packet loss	0%	0.31%	0.3%

Table 3 shows the results of the link quality tests for the integrated network.
The results show that should one of the SU be used the IPTV application, other applications may not use the same SU. The Su's used have a theoretical throughput value of 12Mbps.

B. Future Works

Future work on the platform will involve enabling the DiffServ QoS model on both the routers and the WiMax BS. The Alvarion solution of the BS provides for two options to mapping the MAC layer QoS classes to IP layer, using 802.1p QoS classes, which caters for only 9 traffic classes and the DSCP, which provides for 64 traffic classes. The latter option will be adopted since it accommodates more traffic classes. The proposed QoS mapping strategy will be implemented and the performance of the network evaluated using IPTV, video streaming, VoIP and Data applications. Future research areas on the platform could include implementation of a Linux-based MPLS core network, an overlay network, BB and more content servers. To fully integrate the transport network with the IMS network, it is required that IMS modules be installed in Linux routers.

VII. CONCLUSION

In this paper we present an integration of a unified NGN based on a WiMax Fixed Access Wireless access network working in point-to-multi-point mode with a BS and three subscriber units. The core network is an IP network based on Linux routers. The UCTIMS-client is used as the control layer network. A number of content servers implemented in the UCT CRG lab are used as application services network. The work builds on the current and previous research work within the University of Cape Town Communications Research Group. To address end to end QoS provisioning on the platform, we propose a QoS mapping strategy to enable translation of QoS parameters between the access and core networks. The DiffServ QoS model, common in both networks, is used as the basis for this translation. The platform opens research opportunities in NGN, while making use of open source software packages to build the platform. Future work will involve enabling QoS on the core transport network, configuration of DSCP on the WiMax network and implementation class of service mapping between the two networks and run integrated network service.

REFERENCES

[1] K Knightson "Basic NGN Architecture Principles & Issues" Rapporteur Q3/13 (Architecture) ITU-T Workshop on NGN (Jointly organzed with IETF) Geneva 1-2 May 2005.

[2] M. Toy, H. J. Stuttgen, and M. Ulema, "IP Multimedia System, Infrastructure and Services" *IEEECommunication Magazine,* vol.45, no.7 pp. 66-67, Jul 2007.

[3] 3GPP, "The Mobile Broadband Evolution", *3GPP Release 8 and beyond HSPA+, SAE/LTE and LTE-Advanced*, Feb 2009

[4] ITU-T, "Network Performance Objectives for IP-Based Services", *ITU-T RECY.1541,* 2006

[5] http://uctimsclient.berlios.de.

[6] ITU-T, "QoS and QoE, quality of service and quality of experience, turning communications services and technologies into compelling user experiences", *ITU* Mar 2008.

[7] ITU-T, "Network Performance Objectives for IP-Based Services", *ITU-T RECY.1541,* 2006.

[8] ITU-T, "Framework for achieving end-to-end QoS objectives for IP performance objectives", *ITU-T RECY.1542,* 2006.

[9] Braden, et al., "Integrated Services in the Internet Architecture: An Overview" *IETF RFC 1633,* 1994.

[10] S. Blake, et al. "An Architecture for Differentiated Services", *IETF RFC 2475,* 1998.

[11] NSIS.

[12] Cisco Systems, "IP Class of service for mobile networks" www.cisco.com.

[13] S. Chuck, "Supporting Differentiated Service Classes: Multiprotocol LAble Switching (MPLS)"*Juniper Networks, Sunnyvale,* 2002.

[14] C. E. Rothenburg et. a.l, "A review of Policy-Based Resource and Admission Control Functions in Evolving Access and Next Generation Networks" *Springer Science+Business Media*, 2008.

[15] Skorin-Kapov, et. al "Application-Level QoS Negotiation and Signaling for Advanced Multimedia Services in the IMS", IEEE Communications Magazine vol, 45 issue 77 Jul 2007.

[16] Zhi-Li Zhang at. el., "Decoupling QoS control from Core Routers: A Novel Bandwidth Broker Architecture for Scalable Support of Guaranteed Services", *SIGCOM,* 2000.

[17] L. Lao et. el., Distributed QoS routing for Backbone overlay networks", *http://www.engr.ucm.edu/~jcui/overlay_papers/qson_n etworking2006.pdf*.

[18] F. Baker et. al, " *Definition* of the Differentiated Services Field (DS Field) in IPv4 and IPv6 Headers", *IETF RFC 2474*, 1998.

[19] S. Blake et. al., " Architecture for Differentiated Services" *IETF RFC2475*, 1998.

[20] S. Brim, "Per Hop Behavior Identification Codes" *IETF RFC 2836* 2000.

[21] K. Ishiguro, "Quagga: A routing Software package for TCP/IP networks" www.quagga.net/docs/quagga.pdf

[22] G. Ash, et. al., "QoS NSLP QSPEC Template", *IETF Internet Draft NSIS Working Group,* April 3, 2008

Bessie Malila, an MSC student at UCT, received her BSc (Hons) in Electrical Engineering, University of Zimbabwe, 2000. She has worked for TelOne Zimbabwe as a network engineer specializing in Data Communications Networks. In 2003 she joined Africom, where she implemented an MPLS network, integrating it with other NGN technologies.