Budget-Based QoS Management Infrastructure for All-IP Networks

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Abstract--This paper proposes a Budget-Based management infrastructure, *BBQ*,[1] for All-IP networks to offer end-to-end QoS assurance to their services. In this scheme, the quality bound of each component network is controlled based on a calculated budget plan. End-to-end QoS will be assured by a global QoS management agent. The management issues include software architectures in different layers, class based admission and resource reservation policies, as well as resource management infrastructure, policies, and mechanisms. The objective of this infrastructure is to facilitate network operators to tune their networks with a great flexibility and scalability to achieve their own operational objectives.

Keywords-- All-IP Network, QoS, VoIP.

1. Introduction

An *All-IP Network* uses a single IP based packet-switched network to carry all types of network traffics [1,10,14]. This revolutionary All-IP network not only reduces network deployment and management costs, but also offers a great opportunity opening for various new services that are not possible on the conventional separated networks. However, running time-sensitive services such as VoIP on packet-switched networks may suffer from poor quality problem due to long delay time, large jitter, and high packet loss rate. To make All-IP networks possible, QoS is a critical problem yet to be overcome [3,4,5,13,14].

A Simplified All-IP Network Architecture

Without loss of generality, we assume the following simplified All-IP network architecture. A world-wide All-IP network consists of several core networks interconnected together through some interconnection links (e.g. cross Pacific undersea cables/fibers) and some number of stub networks (also named *access networks*) connected to core networks. A *core network* consists of some *Interior Routers* (*IR*) and some *edge routers*. An *edge router* is also an *Inter-Domain Gateway* (*IG*) if it is connected to another core network. A *stub network* is connected (attached) via an *Access Gateway* (*AG*) to an edge router, called the *Border Gateway* (*BG*), of one (or more) core network. Typical stub networks are WLAN, GPRS, 3G, and conventional local loops. A service request, which may be a phone call, a video stream, or a file transfer, will be converted into IP packets first when it enters the network and be converted back to the original format when it leaves the network. Depending on the admission policy, when a packet is admitted into an All-IP network, it will enters the Entrance stub network, and will be forwarded to the first core network, the second one, etc., to the Exit stub network, and finally to the destination. Although, in reality, a stub network may attach to more than one core network for various reasons such as availability, we assume a stub network only attaches to one core network for simplicity. The network architecture is depicted in the Fig. 1.

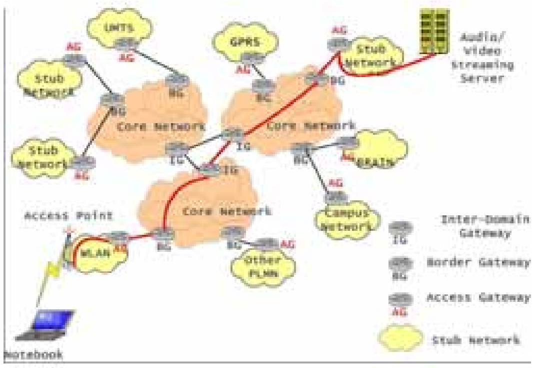

Fig. 1. A simplified All-IP Network Architecture.

Paper Organization

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The related work will be shown in Section 2. Section 3 shows the overall BBQ infrastructure. Section 4 and 5 discuss the QoS management schemes for end-to-end QoS, core networks, and 3G/WLAN, respectively.

2. Related Work

The two most popular QoS technologies are Differentiated Services (DiffServ) and Integrated Services (IntServ) [2,19,20]. The heart of IntServ is RSVP (Resource Reservation Protocol) [19,20]. Before admitting a service request, IntServ first reserves needed sources along the path selected for the request. It can provide end-to-end QoS with higher confidence, but it suffers from scalability due to tremendous management overhead. On the other hand, DiffServ can avoid scalability problem. DiffServ is a protocol for specifying and controlling network traffic by class so that certain types of traffic, such as voice, get precedence [2]. The major advantage of DiffServ is its simplicity and easy to implement. However, the end-to-end behavior is not controlled. Extra mechanisms are needed to enhance the QoS assurance to the end-to-end and per-flow level [18].

The two most famous large scale efforts trying to provide end-to-end QoS for All-IP Networks are TEQUILA and AQUILA [1,4,14]. TEQUILA (Traffic Engineering for Quality of Service in the Internet, at Large Scale) is a project partially funding by the European Commission [14]. The objective of the project is to study, specify, implement and validate a set of service definition and traffic engineering tools to obtain quantitative end-to-end QoS guarantees through careful planning, dimensioning and dynamic control of scalable and simple qualitative traffic management techniques within the Internet (i.e., DiffServ). AQUILA (Adaptive Resource Control for QoS Using an IP-based Layered Architecture) is another European project aiming to provide end-to-end QoS to IP Networks [1,4]. The goal of this project is conception, design and development of an architecture to enable different service classes in the Internet.

3. Management Architecture

3.1. Design Philosophy

Budget Based QoS Management

Based on the simplicity principle, BBQ requires each network component be able to guarantee a committed quality. The quality bound of each component network is controlled based on a calculated budget plan. End-to-end QoS will then be assured by a global QoS management agent, which will be discussed later. We assume each network router has DiffServ like capability. BBQ is actually a software layer above DiffServ domain. DiffServ routers take instructions from the QoS managers of upper layers and set the appropriate DiffServ parameters and QoS policies.

Pre-Planning vs. On-Demand Managements

In order to maximize network performance and to minimize service response time, many of management mechanisms in BBQ, such as resource allocation and reservation, take pre-planning approach, instead of real-time on-demand approach.

Pre-planning approach requires an accurate traffic forecast. Previous study shows that aggregated traffic on core networks usually demonstrates some repeated statistics pattern. For instance, the traffic statistics of most Monday noon are very similar. Based on this assumption, a network planner could use historical traffic statistics to forecast incoming traffics in the future. The granularity of the time interval between two forecasts can be determined by the operators based on real network traffic statistics. On the other hand, the forecast error caused by the inevitable traffic fluctuation may hurt the management objectives. In this project, we propose several methods to compensate the performance degradation caused by forecast errors [12].

Class Based Service Policies

For time-sensitive and connection-oriented (TSCO) service requests such as Conversational and Streaming classes, the admission control agent in BBQ will proceed with a light weight *call setup procedure* to designate a path and to reserve the required resources to assure the demanded end-to-end quality. For other types of services, BBQ does not reserve any resource. Instead, it takes best-effort policy to serve time-insensitive services. Operators determine their class-based pricing structure to maximize their operation objectives, while users choose appropriate service classes based on the demanded quality and the costs they are willing to pay.

Path Centric Per-Flow End-to-End QoS Assurance

To ensure end-to-end QoS for a TSCO service request, the admission control agent designates to the request a pre-planed path with sufficient resources reserved. All packets of the same TSCO request are delivered along the designed path. Since the quality of each link is guaranteed, a controlled path will be able to guarantee the end-to-end quality level. In this way, per-flow end-to-end QoS is guaranteed. This path centric QoS mechanism is similar to the virtual circuit in some network components such as ATM. However, the end-to-end paths in BBQ are only pre-calculated, but not reserved until individual service requests arrive.

To reduce real-time overhead in the resource reservation procedure, we partition the reservation into two phases. In the first phase, pre-planning phase, each edge router of each core network is allocated with certain amount of *short-paths*. A short-path is a path from one edge router to another in the same core network. Each short-path has bandwidth reserved and quality level guaranteed. At the second phase, the time of admission, the admission control agent first selects a pre-planed end-to-end path that meets the bandwidth and quality requirements, and proceeds with short-path reservations. Since an end-to-end path may travel only a handful core networks, the real time overhead for the reservation procedure can be greatly reduced as compared to the conventional link based reservation such as IntServ/RSVP protocol. The detailed design will be shown later.

3.2. Bearer Service Hierarchy

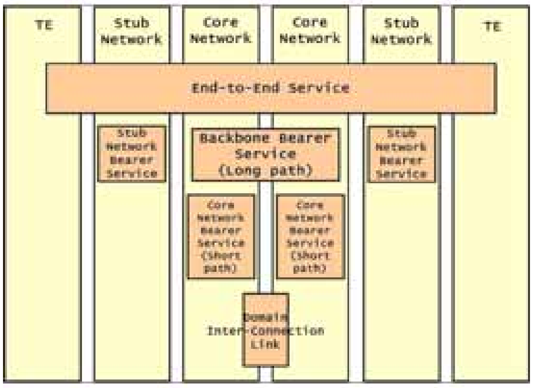

Fig. 2. Bearer Service Hierarchy

As depicted in Fig. 2, an end-to-end service is carried by many smaller bearer services. Each core network provides a short-path bearer service, and a long-path is the combination of all short-paths that a packet travels. Adding together the bearer services provided by the Entrance and Exit stub networks, an end-to-end bearer service is formed. In this way, with piecewise QoS assurances provided by smaller bearer services, the end-to-end QoS is guaranteed.

3.3. QoS Management Hierarchy

Table 1 shows the QoS management hierarchy in BBQ. Based on the simplicity principle, BBQ organizes the software agents in different network components into layered management hierarchy. The end-to-end QoS assurance responsibility is then decomposed into smaller pieces and distributed to many agents in different layers. With autonomous authority within the designated responsibility, each agent may make some decisions by themselves without any negotiation with other entities. The response time to a service request can be greatly reduced while the resource efficiency can be maintained.

Table 1. QoS Management Hierarchy

Management Layer	**Managing Agent**	**Responsibility**
End-To-End Resource Coordination	Long-path planning agent of each core network	plan long-paths with various quality level and provide information for long term network capacity provisioning
End-To-End QoS Control	admission controller of Entrance stub network	select appropriate end-to-end paths, short-path reservation, and perform admission control
Sub-Network Resource Management	Bandwidth Broker of each core network	allocate resources, e.g. bandwidth of links, to the resource mediators, e.g. edge routers in a core network, RRM in a 3G access network.
Sub-Network QoS Control	admission controllers of each stub/core network	execute the QoS policy of the sub-network, e.g. admission control, load control, routing and path selection, packet scheduler, etc.

4. End-to-End QoS Management

The most important task in the End-to-End QoS Management functionality is to plan a set of long-paths to meet the quality requirements for anticipated service requests. Core network operators then provision their own core networks based on the forecasted demand. Since an All-IP network is a federation of many sub-networks, we assume there is no any global network planer existing to plan the entire network from the global viewpoint. Network planning has to be performed by all core network operators in a cooperation (distributed) manner, instead.

4.1. Long-Path Planning

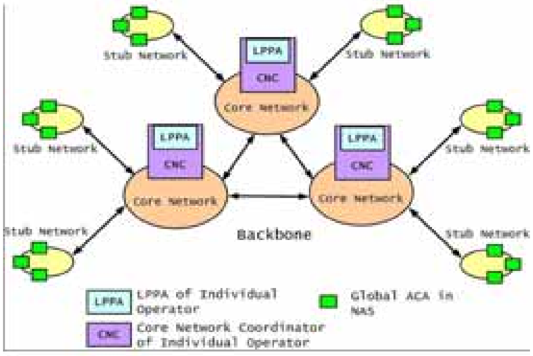

Fig. 3. Long-Path Planning Agents

As depicted in Figure 3, each core network has a *Core Network Controller* (CNC) to perform all centralized management operations. One important component in CNC is the *Long-Path Planning Agent* (LPPA). The LPPAs of all core networks work together to compute all possible long-paths that meet the QoS requirements of potential requests. Based on the obtained results and the traffic statistics, the agent forecasts the capacity demand for the short-paths it may use in the future time slots. The long-path planning procedure is as follows:

1. Each core network publishes the specification of its short-paths.
2. The LPPA in a core network computes the best long-paths for all potential service requests that will be originated from this core network.
3. Based on the computed results and the traffic statistics, the agent forecasts the capacity demands for the short-paths it may use in the future.
4. Each core network collects forecasted demand for short-paths and provisions the network with sufficient capacity.

Note that it is impractical to make long-path reservation at this stage since a long-path may cross several core networks in several different countries. Long-path planning in BBQ is only a procedure to compute end-to-end paths and to forecast bandwidth demand for network operators to provision their networks.

4.2. Global Admission Control Procedure

To reduce call setup time, The global ACA at an Entrance stub network uses a light weight on-demand procedure to reserve a long-path for each request:

1. From the long-path table, select an appropriate long-path.
2. Reserve a short-path from each of the core, Entrance, and Exit stub networks.
3. If fail, try another alternative long-path.
4. If no path is available, reject the request.

Since a long-path may travel only a handful of core networks, the overhead for the above procedure will be very low so that it is applicable for large scale networks. The selection of appropriate long-paths for service requests is a typical optimization problem. We model the problem as an integer programming problem and relax it into a linear programming problem. The objective is to minimize the penalty cased by unsatisfying aggregates of traffic subject to the constraints of (1) fixed resource (Limited Short Path bandwidth); (2) traffic aggregate QDF budget must be satisfied; (3) allocate resource to traffic aggregates; (4) trading off QDF with bandwidth in each short-path.

4.3. QoS Management for Core Networks

A core network is owned and operated by an independent operator. Under BBQ infrastructure, each core network is responsible to provide many QoS assured short-paths. The traffic that is admitted into a short-path will travel along that short-path so that its quality will be guaranteed. The Global ACA of each stub network will perform admission control so that it will not send too much traffic to the network. Under this circumstance, each core network will be able to guarantee the QoS level for all admitted traffic flows.

To speed up the real-time admission procedure, each edge router is pre-allocated with some short-paths and equipped with an admission control agent (ACA) to perform the admission control autonomously. BBQ proposes several resource allocation mechanisms to best utilize network resources in order to achieve the maximum performance. The details can be found in [11,12].

5. QoS Management for Stub Networks

5.1. QoS Management for 3G Radio Access Network

We have a detailed design of the functionalities of Radio Resource Manager (RRM) in Radio Network Controller (RNC) [6,7,8,9]. We also proposed a composite traffic model for UMTS considering those factors of radio power, environment, user movement behavior and varied service requests. The traffic model is expected to be able to analyze and trace the real traffic of the UMTS system.

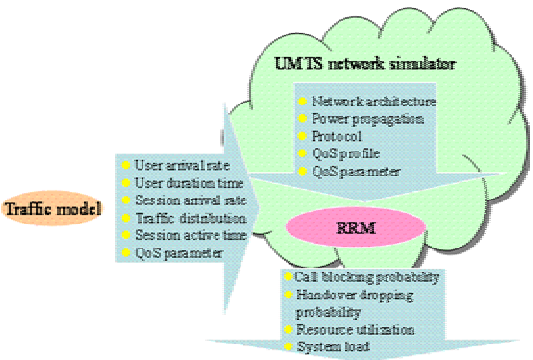

Fig. 4. Data flow among traffic model, UMTS network simulator and RRM.

RRM consists of five components which are admission controller, load controller, handoff controller, power controller, and packet scheduler. These functions together are responsible for supplying optimum coverage, offering the maximum planned capacity, guaranteeing the required quality of service (QoS) and ensuring efficient use of physical and transport resources.

We differentiate services into distinct QoS classes, design the functionalities of RRM components and their mutually supporting interrelationships, select the most appropriate channels doing data transmission, and optimize resource (power and bandwidth) allocation assuring QoS with packet loss, delay, and jitter under constraints.

5.2. QoS Management for WLAN

QoS Management scheme for WLAN is discussed in this section. We assume that the WLAN mobile clients can access to the nearest access point not only via single-hop but also multihop forwarding. There exist also the wireless enabled MANs for the WLAN ISP backbone such that mobile clients can roam among different access points and also be under control of certain QoS.

For the past few years, IEEE 802.11b products have massively occupied another wireless data market in a very short time. The data rate is becoming very high (54Mbps for 11a /11g). It is no doubt more and more wireless applications that require higher bandwidth and quality of service (QoS) will be developed and noticed attractively. The integration of key components of QoS-provisioning techniques on wireless data service platforms will become increasingly important.

Under our BBQ infrastructure, we differentiate service priorities for different applications with different bandwidth requirements at the call setup time. Referring to UMTS/3GPP service classes, we have developed a mathematical QoS model to analyze delay and loss for choosing admission policies, resource management mechanisms and the mapping between application and service classes [17]. In IEEE 802.11e, Enhanced Distributed Channel Access (EDCA) is used to differentiate service of priorities by means of various Inter-Frame Space (IFS) and Contention Window (CW). In order to develop efficient QoS management schemes for the IEEE 802.11e networks, we propose an analytical model to evaluate throughput and MAC delay under different multimedia traffic flows, namely, voice, video, and data. Throughout our model, call admission control (CAC) and resource management can be easily applied, and thus QoS for hybrid requirements is supported.

For control of bandwidth allocation for different classes of traffic, we have developed a new MAC protocol for differentiated QoS support [15] and also utilized the CBQ (Class-Based Queueing) functionality on the access points to control bandwidth.

We further study on influences of the large interference range and TCP instability/fairness problems. We proposed an adaptive IEEE 802.11 RTS/CTS control mechanism to improve the throughput and thus QoS.

Finally, for public WLAN roaming users, IAPP (Inter-Access Point Protocol) is utilized to support seamless roaming, and moreover is modified to maintain certain QoS during handoff transition periods [16]. We also developed an in-building 802.11b locating and tracking system to help predict handoff and thus we can reservation bandwidth for roaming users in advance.

A simple prototyping was implemented with the above key features, including IAPP, load balance, seamless roaming, CBQ bandwidth control and the locating system. The MAC protocols, including modified RTS/CTS, and access scheduling are evaluated through simulation results.

6. Summary

This paper proposes a Budget-Based management infrastructure, BBQ, for All-IP networks to offer end-to-end QoS assurance to their services. In this scheme, the quality bound of each component network is controlled based on a calculated budget plan. End-to-end QoS is assured by a global QoS management agent. We designed a software architecture in layer manner each playing various roles, some class-based admission and resource reservation policies, a resource management infrastructure, some management mechanisms such as QoS based routing model and algorithms, as well as resource allocation models and tools. This infrastructure and the associated tools will facilitate network operators to tune their networks with a great flexibility and scalability to achieve their own operational objectives.

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