

CHAPTER 2

Challenges in Design of Next Generation Networks

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Abstract. *Low rate high latency data services will co-exist with high rate low latency real-time multimedia applications in the next generation networks. Increasing volume of multimedia flows in an environment with heterogeneity in bandwidth, propagation medium and statistical characteristics of traffic can be expected to generate time-varying demands on the quality of service (QoS) and network resources. In such non-stationary environment, dynamic resource reservation schemes operating in harmony with the variability in demand patterns may provide efficient mechanisms for resource utilization and guarantee QoS compliance. In this work we identify the challenges that need to be addressed in designing a three level core, distribution and edge (CDE) hierarchical network using time-varying resource allocation mechanisms. Learning, prediction and correction (LPC) architecture based upon integration of operational CDE network with online simulation proposed as a design alternative to contemporary networks.*

1. INTRODUCTION

The support for heterogeneity in services, participating network devices and transportation medium is driving the evolution of the next generation communication networks (NGN) [1]. The traffic in NGN is required to be supported on relatively unconstrained desktop computers as well as over personal devices that may be constrained by power, processing capability and bandwidth availability. The propagation medium is increasingly non-uniform varying between wired and wireless environments. The traffic is increasing in volume and exhibiting non-stationary statistical behavior. In the midst of increasing heterogeneity, expectations from the network regarding the quality of the delivered services are becoming more demanding than ever. The real time traffic such as voice, video or multimedia is driven by different quality of service (QoS) requirements. Due to variability in contribution of each traffic class to the aggregate traffic pattern, the QoS constraints can be expected to vary with time. Current QoS sensitive resource allocation schemes are based upon network flow classification and priority based queuing/admission control mechanisms. Resources allocated along the transmission path may be fixed for a user or for a type of data-flow. For example, resource assignment in digital subscriber line (DSL) is fixed at the time an access is provisioned. Instead, an architecture that provides mechanisms that allow rates to be selected or changed more often, potentially on-the-fly may be preferable [2]. QoS control based upon resource reservation schemes [3]-[6] guarantees availability of "tunnels" of predetermined bandwidth for the desired traffic types identified by "labels". Though the reservation may adapt dynamically to changing number of multicast users and routes as suggested in [25], it may not respond to fluctuations in user requirements and remain fixed for the lifetime of the flow. Once the resource allocation is made, network conditions may change considerably over time resulting in the availability of alternative, more efficient resource allocation strategies. Consequently, static allocation schemes may result in inefficient resource utilization and scale poorly in presence of increasing volumes of multimedia traffic. To support QoS compliance in next generation networks, some fundamental changes in the core, distribution and edge (CDE) network technology may be required. This paper identifies the factors that may trigger changes in the current CDE fabric to support the QoS compliant services in NGN. Online simulation supported by demand prediction and learning models may prove to be viable tools for design, deployment and refinement of the current CDE technologies. An alternative network design that continuously predicts, corrects and learns

the network configuration parameters is proposed. The proposed architecture is based upon integrating the operational CDE network with online simulations. The research challenges arising from these changes are discussed and a possible future direction of network evolution is outlined.

Section 2 outlines the architecture and the design problem considered in this work. Section 3 describes the issues in the present environment that may make the design changes in the CDE network necessary. Section 4 discusses present QoS implementation techniques and Section 5 describes the proposed enhancements to the present technology. Section 6 concludes the paper.

2. QoS COMPLIANT NETWORK

2.1 Architecture

Contemporary networks are based upon the concept of a hierarchical three tier architecture comprising of Core, Distribution and Edge (CDE) networks. The core network is typically supported over wired or fiber-optic connections. Distribution and edge networks are a heterogeneous combination of wired, wireless and/or free-space optical links connecting end-users to the core network. The input traffic from all end-users is collected by the edge network and then forwarded to the distribution network. Several such distribution networks feed the traffic to the network core. In the reverse direction, the distribution network takes the input from the core and distributes the traffic to the intended users connected to the edge network. Such a hierarchical architecture is pervasive in today's networks and can exist at several levels. At global level, an optical core can pervade across several continents and nations. At national level, a core network may connect several cities. At an organizational level, for example, in a university, the core network can feed several functional units such as campuses or colleges. The end users for the core network in each case may vary depending upon the level of the core and distribution network of interest. At the organizational level, end user pool may comprise of individual users. For a national or global level core network, the end-users may be the Internet service providers (ISPs) or organizations with inter-continental/international presence.

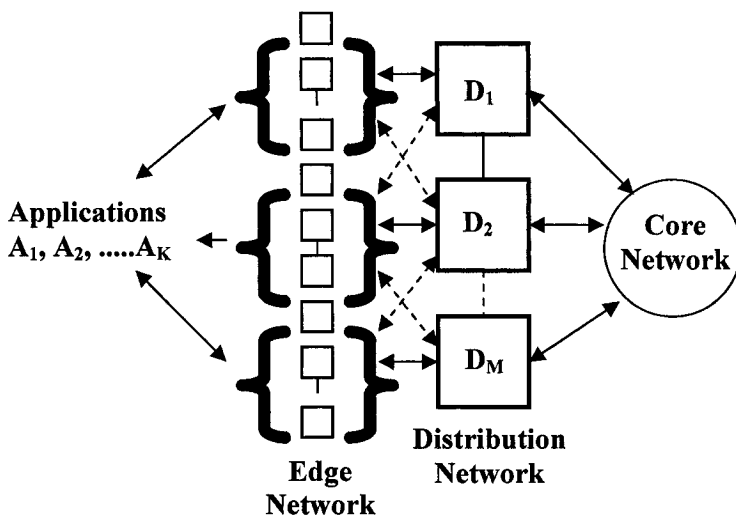


Fig. 1 Core, Distribution, Edge (CDE) Network Architecture

Fig. 1 shows the three-tier CDE network architecture. The core is connected to several nodes D_i , $i=1,2,\dots$ in the distribution network. Each node D_i acts as a collection and distribution center for the traffic originating from and destined to the nodes E_i , $i=1,2,\dots$ in the edge network. The edge network may be connected to one or more distribution nodes through a primary path shown by solid lines and several alternate links shown by dashed lines. Multiple connections between edge and distribution network nodes may share the network load to ensure adequate load-balancing and provide redundant connectivity for improved reliability. The input traffic at each edge node comprises of an inhomogeneous mix of *delay sensitive* real-time traffic like video and voice in conjunction with *delay-insensitive* services such as e-mails. The multiplexed traffic generated by applications A_i , $i=1,2,\dots$ serves as an input to node E_1 located in the edge network and may be destined towards another user connected to node E_2 . If both the edge nodes E_1 and E_2 are connected to the same distribution node D_i , the traffic may follow a path $E_1 \rightarrow D_i \rightarrow E_2$. If the nodes E_1 and E_2 are connected to different distribution networks at nodes D_i and D_j , $i \neq j$ respectively, one of the possible paths the traffic could be sent is $E_1 \rightarrow D_i \rightarrow C \rightarrow D_j \rightarrow E_2$ through the network core C.

Packets transmitted by users are received at each of the intermediate nodes along the communication path and stored until the next link is free,

and then forwarded towards the intended destination. Such communications incur delays, jitter in the output stream and may yield an unacceptable traffic quality at the destination. Unacceptable quality may refer to high transmission delays and error rate that are in excess of the delays and errors introduced by the transmission medium [26]. The primary reason for these delays is unavailability of sufficient network resources such as bandwidth, buffer-space and processing power/capability at one or several nodes/links in the CDE network hierarchy. Increased real-time traffic in future networks may be expected to drastically change the Internet traffic profile and impose more stringent delay and jitter requirements. One way to deal with traffic inhomogeneity is to provide resource reservation for each flow along the communication path. This approach works well only when traffic patterns and quality of service requirements are known, for example as time-averaged statistical metric. Due to variability in the number of network users and generated traffic patterns, reservation based approaches are likely to result in inefficient resource utilization. To support real-time services, a need for extending the present network architecture may be necessary.

2.2 Design Problem

Let the QoS requirements for each application A_i be defined by a vector $Q_i = [Q_i^1, Q_i^2, \dots, Q_i^N]$ comprising of N possible QoS descriptors. The descriptor Q_i^k describes the QoS requirement of the k^{th} traffic stream generated by the i^{th} application. For example, a network download application involving download of a data-file and real-time video may be characterized by different quality guarantees represented by Q_i^1 and Q_i^2 respectively. In general, the QoS descriptor $Q_i^k = f(b_i^k, p_i^k, D_i^k, d_i^k)$ may be represented as some function $f(\cdot)$ of bandwidth b_k , acceptable probability of error p_k , delay D_k and jitter d_k . All QoS parameters can be combined into effective bandwidth B_i^j representation [9] resulting in $Q_i = [B_i^1, B_i^2, \dots, B_i^N]$. Depending upon resource allocation policies, effective bandwidth can be a function of space related parameters such as buffer size/occupancy and probability of buffer-overflow, and time related parameters such as delay and jitter. Effective bandwidth can be computed as the bandwidth shared at a node by multiplexed sources and is asymptotically bounded by a desired queue length and delay [9,10]. Using exponential bounds for queue length and delays, several approximations for effective bandwidth can be derived for traffic characterized as periodic sources, fluid sources, Gaussian sources and general on-off processes [9]. These approximations

may be adequate only for small buffer-overflow probability and large buffer-size [10].

When an application is invoked, several traffic streams may be active either simultaneously or intermittently. An application such as an Internet browser may initiate downloads of real-time audio, video, e-mail as a function of time, each requiring different QoS guarantees. As a result, the QoS requirement of an application will vary temporally and can be described by a vector $Q_i(t) \subseteq Q_i$, where \subseteq denotes a subset. The contemporary approaches to guarantee QoS compliance are based upon a-priori resource reservation schemes [3,4]. Prior to initiating communication, a network path is assigned such that the effective bandwidth requirements for the application are met. Consequently for A_i , the assigned bandwidth at the j^{th} intermediate node along the communication path follows

$$\sum_{k=1}^{N_i(t)} B_i^k \leq B_i^k(t), j=1,2,\dots \quad (1)$$

where, $B^{Ej}(t)$ on the right hand side denotes the bandwidth assigned at a node E_j in the edge network at time t for the number of active traffic flows $N_i(t)$. The cardinality of the vector representing QoS requirements of A_i is assumed to be $|Q_i(t)| = N_i(t)$, $N_i(t) \leq N$ and as a function of the generated traffic pattern that changes with time. In general, the bandwidth assignments in Eq.(1) should hold for all the intermediate nodes in the core, distribution and edge networks for all time instants $t:[0:\infty]$.

When a node supports several applications, the resource allocation over these applications is constrained by the capacity of the node. The demand on node E_j at time t can be specified in terms of the number of applications $M^{Ej}(t)$ supported at the node E_j at an instant t as

$$D^{Ej}(t) = \sum_{i=1}^{M^{Ej}(t)} B_i^{Ej}(t). \quad (2)$$

$M^{Ej}(t)$ is assumed to be less than or equal to the total number of applications M that can possibly be supported on the network. For all time instants $t:[0:\infty]$,

$$D^{Ej}(t) \leq C^{Ej}, j=1,2,\dots \quad (3)$$

where, C^{Ej} denotes the capacity the edge network. The relationship expressed in Eq.(3) must hold for resource assignment at core and distribution networks as well. When the traffic exceeds the node capacity or exhibits any deviation in QoS requirements from the contracted QoS, traffic shapers [7] can be used to guarantee Eq.(3).

The resource allocation problem in Eq.(1) can be cast in terms of several optimization problems subjected to capacity constraint in Eq.(3). For example, resources can be allocated to maximize the number of multiplexed traffic streams $N_i(t)$ for an application; maximize number of applications $M^{Ej}(t)$ supported at a node with a fixed/known $N_i(t)$ and/or minimize resource consumption collectively at all nodes (or at each node) for a given number applications and traffic patterns. The optimization is presumably a highly complex operation due to large number of applications and potential routing paths available.

Communication networks are inherently evolutionary in nature and non-stationary in time. Considering long lifetime of communication networks, the maximum possible applications and traffic streams M and N respectively may also show variability, albeit at a very large time-scale. Assuming M, N as constant, the number of applications $M^{Ej}(t)$ at a node and/or the associated QoS descriptors $N_i(t)$ for the i^{th} application may change over short intervals of time. Co-existence of multimedia and non-multimedia flows can potentially result in a very large range of variability in QoS demands. In response to variability in $M^{Ej}(t)$, $N_i(t)$, the bandwidth allocation $B_i^{Ej}(t)$ may require adaptation throughout the CDE network to maintain the QoS and the integrity of relationships in Eq.(1), (3). In response to changes in demand at time t , the resource adaptation may be feasible only after an interval Δt due to processing and propagation delays inherent in the network. To support real-time applications, one of the design goals could be to *make the interval Δt as close to zero as possible*. The resource allocation for an application must be addressed in a broader context of efficiency of overall resource allocation to maximize of simultaneously supported applications and QoS classes. Consider the residual capacity of node E_j at time t to be

$$R^{Ej}(t) = C^{Ej} - D^{Ej}(t). \quad (4)$$

Variability in traffic patterns and network usage may result in the demand $D^{Ej}(t+\Delta t) \gg R^{Ej}(t)$ exceeding the residual capacity of the node at time $t+\Delta t$. This may occur due to increase in the number of the existing applications rendering $M^{Ej}(t+\Delta t) > M^{Ej}(t)$, or, the change in quality

commitment required by the network due to changes in the number of quality descriptors $N_i(t+\Delta t)$ characterizing the existing applications. Excess demand generated by new applications can be curtailed by filtering all the input flows through admission control algorithms [8] and excess demand generated during the life-time of existing applications can be clipped by traffic shaping algorithms [7]. Such admission control and/or traffic shaping approaches may result in inefficient resource utilization when several nodes collectively are able to satisfy the new demand yielding

$$D^{Ej}(t + \Delta t) \leq \sum_j C^{Ej}. \quad (5)$$

To accommodate changes in demand and efficiently utilize the excess capacity distributed across several nodes will require redistributing new and existing applications between alternate available nodes. We envisage that NGN will have the flexibility to "context switch" the applications/traffic across network nodes similar to modern distributed operating systems that are capable of context switching between several processing units. Current technology may be enhanced using reactive or proactive approaches for dynamic resource allocation. A reactive method computes resource allocation at time $t+\Delta t$, $\Delta t > 0$ *after* the change in demand is experienced at time t . In a proactive solution, resources may be reserved at time $t-\Delta t$ in anticipation of changes in the demand patterns *before* the actual demand arises at time t . A reactive approach may satisfy QoS requirements for delay insensitive applications and proactive solution may be a promising alternative for delay sensitive real-time applications. The expected benefits from such a scheme are improved resource utilization and support for larger number of users/applications.

3. CHALLENGES IN QoS BASED DESIGN

Development of an efficient resource allocation plan requires scalability of resource allocation policy with network variability. Temporal variability in network conditions can be primarily attributed to traffic non-stationarity, bandwidth asymmetry and heterogeneity in QoS requirements for users. Each aspect is discussed in this section.

3.1 Traffic Non-Stationarity

The current communication environment is marked by an unprecedented growth in the number of users and traffic volume. To estimate the future growth patterns, one way is by using the growth trends in the past as indicators. ARPAnet between 1971-75 [21], number of Internet hosts between 1981-2000 [32], and the world-wide-web (WWW) traffic [12,20,22] has shown exponential growth patterns. Different protocols contributing to aggregate traffic show strong variation with time [12] and sites [13,14]. Traffic in the future is projected to be an aggregation of telephonic, multimedia, and Internet traffic with the contribution of each traffic class being a function of the growth in the respective domain [23]. Data traffic is projected to exceed voice traffic volume over the next few years [24]. The increased traffic volume may be attributed to improved penetration of communication technology for business, educational and entertainment purposes. The growth in the number of users and variation in their usage profile is promoting spatial and temporal diversity in the traffic volume and aggregate traffic patterns. The key to success in bracing these changes lies in understanding the viability, efficiency and flexibility of the present technology in adapting to heterogeneity in traffic volume and profile. Due to complexity of performance analysis tasks involved and possibly large margins of errors in projections of future trends, simulation based analysis aided by traffic modeling may be a promising approach to allow telecommunication technology to evolve with the growth in demand.

Poisson queuing models pioneered by A.K.Erlang [35] are traditionally used to describe the network traffic. As communication networks are maturing towards providing high-rate multimedia services, the traffic patterns are evolving from simple mutually independent Poisson arrivals to self-similar traffic patterns. Long-tailed inter-arrival time distributions and self-similarity in the traffic over, theoretically infinite range of time-scales, were Paxson and Floyd's key findings [11]. Analysis of traffic flows generated by user interaction with distributed systems [36-39] and measurements for wide and local area networks [40-43] has revealed existence of random, bursty traffic patterns, clusters of packets and hyper-exponentially distributed times of user dialog. Temporal dependence in traffic resulting from self-similarity has resulted in a need to re-evaluate network designs that evolved around Poisson traffic models. These traffic patterns may not readily map to pure stochastic model framework. Complex large-dimensional stochastic models or approximations leading to simpler models may be required to understand and characterize the traffic in NGN.

3.2 Bandwidth Asymmetry

Bandwidth asymmetry results due to higher bandwidth in the forward direction from a server/router to a host as compared to the backward direction from a host to a server/router. Due to asymmetrical bandwidth, latencies in upstream and downstream directions may differ drastically resulting in severe performance bottlenecks [15]. Asymmetrical routes may result when different routes are pursued by upstream and downstream traffic, consequently aggravating the propagation delays [16]. Heterogeneity may exist due to interactions among different protocols, different levels of load and congestion in different parts of the network, topological differences and variation in traffic patterns generated at a site and across different sites [45]. Network asymmetry exists in the capabilities of the end-user that may range from resource-starved personal digital assistants (PDAs) to powerful desktop machines. Network asymmetry poses a formidable challenge in reaching QoS targets [15-19]. TCP, that is the most widely used protocol in today's networks, is adversely affected by these asymmetries due to its inherent feedback mechanism based upon transmission and reception of acknowledgement packets (ACKs). Poor TCP performance can be expected when ACKs are lost or congest the network due to bandwidth asymmetry or incur disproportionately high cost in one direction. Several techniques such as header compression or rescheduling of packet transmissions have been proposed to mitigate effects of bandwidth and medium asymmetry [15] [19].

In addition to performance of underlying protocols, the quality of delivered data is highly dependent upon the quality of wireless links in heterogeneous wired/wireless networks. In current deployments, the service level agreement with a mobile internet user may be difficult to satisfy due to limited resource availability in parts of the network the mobile user may be moving into. Wireless links transition from favorable channel conditions where communication may be as good as the wired link, to unfavorable conditions where errors become highly probable. There is a need to identify new methods to guarantee QoS in such hostile propagation environments. Cross-layer design approaches combining functions of several network layers and adapting parameters based upon multi-layer feedbacks may be one of the solutions [60].

3.3 Heterogeneous QoS Requirements

Real-time applications like video and voice exhibit low tolerance to latencies and jitter compared to traffic such as e-mail and data-exchange. Due to variable bit rate behavior, real-time traffic flows exert time varying demands on the network resources. For example, the QoS demand generated by i^{th} application may comprise of video and voice traffic and can be represented as a vector $\underline{Q}_i = [B_i^1, B_i^2]$ where, B_i^j represents the effective-bandwidth requirement for the j^{th} traffic type. Bandwidth $B_i^{\text{Ek}}(t)$ required to route the traffic through node E_k may change with time as voice or video or both are transmitted. One way to deal with demand variability is to allocate $B_i^{\text{Ek}}(t)$ equal to the maximum demand $B_i^{\text{Ek}}(t) = \text{Max}[\sum_j B_i^j]$ or average demand $\text{Avg}[\sum_j B_i^j]$. When the variability in the demand is very high, such an allocation scheme may result in under-utilization of network resources. Alternatively, the bandwidth allocation may be computed as a function of time to be approximately equal to the demand $D_i^{\text{Ek}}(t)$. Amongst contending traffic, time varying resource allocation may be done with preferential or deferential unfairness. Real-time applications, such as voice or interactive video, can be given priority or preferential services avoiding severely penalizing data applications. Undesirable traffic in the network such as denial-of-service, worm-generated traffic or web surfing to destinations exists in the network. Though, these flows may contain real-time video, voice traffic traditionally classified as services requiring high QoS levels, may not merit preferential treatment.

Different users supported by the network may have different perspective of service requirements from the network. From the Internet service providers' viewpoint, designing network functionality based upon cost measures such as maximum bandwidth utilization may be desirable. Such cost-centric approach towards network design may not always result in desirable QoS levels from the end-users perspective. To obtain the appropriate levels of service for individual users through efficient the bandwidth allocation may be done in accordance with the demand patterns. The number of supported users may be maximized by the utilization of the excess capacity.

4. GUARANTEEING QoS in CONTEMPORARY NETWORKS

The current approaches adopted in contemporary networks to guarantee QoS are outlined in this section.

4.1 Methodology

Achieving QoS through resource reservation is described in [3]. Classification is the first QoS function to occur, often repeatedly at various stages of policy enforcement. The incoming packets are classified at the router into flows. All packets belonging to the same flow obey a predefined rule, have similar quality requirements and receive identical service by the router. In the next step, based upon packet markings received during the classification phase, packets might be discarded by a policer or a congestion-avoidance mechanism. Packets that are not discarded are subject to queuing to prioritize and protect various traffic types when congestion happens to the transmission link. These packets are scheduled for transmission on the egress link, where shaping might occur to control bursts and ensure that outgoing traffic conforms to any service level agreement (SLA) that is in effect on the ingress of the next hop. Congestion-avoidance mechanisms and queuing algorithms may be deployed during this phase to ensure quality compliance. Queuing/scheduling algorithms manage the front of a queue, whereas congestion-avoidance mechanisms manage the tail of a queue.

Despite use of congestion-avoidance mechanisms, network congestion is a common occurrence. Whenever packets enter a device faster than they can exit it, the potential for congestion exists. Congestion-management such as packet compression or fragmentation apply to interfaces that may experience congestion. This could be the case in either a WAN or a LAN environment because of speed mismatches between ingress and egress links. Large data packets may require fragmentation and interleaving to minimize delay incurred at the network interfaces waiting for resources to become available. Smaller packet sizes typically allow usage of small, intermittent availability of resources at network interfaces and consequently reduce the delay/jitter.

4.2 Technologies for QoS Implementations

Mid-90s witnessed an evolution of best effort services into integrated services model. Integrated services requires all the participating network elements such as links and IP routers residing in the propagation path to support mechanisms to control the quality of service delivered to the transmitted packets. QoS requirements are communicated by the application to the network either through controlled-load services [26] or guaranteed services [27]. For controlled load services, clients requesting services provide an estimate of the traffic volume generated, in return benefiting from the reserved network resources provided by the network. The client may be denied service by the network in absence of adequate resources. Guaranteed service support is designed for continuous fixed rate network flows and ensures bounded maximum queuing delay and bandwidth. Resource reservation setup protocol (RSVP) [3] is responsible for allocation and maintenance of network resources along the transmission path during the entire life-time of the transmission.

Differentiated services model was introduced in the late 1990s to address deficiencies of integrated services. As against integrated service that is based upon flow-based resource reservation, DiffServ uses packet markings to classify and treat each packet independently. Features such as expedited forwarding [28,29] to provide a strict-priority based service; assured forwarding [30] with markdown and dropping schemes for excess traffic; class selectors [31] to provide code points that can be used for backward compatibility with IP precedence models are incorporated in DiffServ model. Although the DiffServ model scales well to the internet, it offers no specific bandwidth guarantees to the packets.

In the post DiffServ era, more sophisticated techniques, such as Multiprotocol Label Switching (MPLS) and Virtual Private Networks (VPNs) were proposed. The first major deployment of RSVP technology came with Multiprotocol Label Switching (MPLS) traffic engineering (TE). MPLS traffic engineering automatically establishes and maintains label-switched paths (LSPs) across the backbone by using RSVP to establish and guarantee "tunnels" of predictable bandwidth. RSVP operates at each LSP hop and is used to signal and maintain LSPs based on the MPLS TE calculated path [3,4].

In the recent years, QoS paradigms for wired networks are evolving to support QoS on wireless networks. The QoS control for wireless networks includes management of medium access and physical layer functionality.

IEEE 802.11e standard [46,47] specifies enhancements to the medium access protocol for IEEE 802.11 a, b and g standards to enable QoS support for different traffic classes in local area networks (LAN). IEEE 802.11e provides traffic classification, improved channel access and packet scheduling functions and QoS signaling that assists the resource reservation for the specifies traffic stream.

IEEE 802.16 broadband wireless access standard aims to provide fixed wireless access between the subscriber station (residential or business customers) and the Internet Service Provider (ISP) through the BS. The medium access control (MAC) is built to accommodate a point to multipoint topology. The MAC addresses the high-speed QoS requirements with a flexible design of uplink channels from mobile station (MS) to base-station (BS) and downlink channels from BS to MS. The BS has full control on the bandwidth allocation on both channels. Access allocation is provided by the BS via a request-grant mechanism where the MS explicitly requests access. The principal mechanism of IEEE 802.16 standard for providing QoS support is to associate a packet with a unidirectional flow of packets that provides a particular QoS. QoS provisioning is provided for real-time applications with constant bit rate (CBR) such as voice over IP; real-time applications with variable bit rate (VBR) such as streaming video and audio; non-real-time applications which require better service than best effort, such as high-bandwidth FTP.

The IEEE 802.15 group focuses on standards that will cover Wireless Personal Area Networks (WPANs). So far IEEE 802.15 has introduced one standard, referred to as IEEE 802.15.1, which standardized parts of Bluetooth. In addition, the group works on additional standards that will include a high data rate WPAN, referred to as IEEE 802.15.3, and a low data rate WPAN, referred to as IEEE 802.15.4. The group is also developing recommended practices to facilitate the coexistence of IEEE 802.15 and IEEE 802.11, referred to as IEEE 802.15.2. The QoS paradigms considered in these standards include channel access scheme combined with flow classification to enable a certain level of QoS support. There are a number of QoS mechanisms (i.e., admission control, packet scheduling) that are still undefined and the network designer may implement per-flow QoS solutions for which the standard defines some necessary QoS mechanisms such as per-flow classification. Some of these standards also provide optional priority that may be used to implement differential services.

4.3 Simulation and Measurement Based Analysis

Simulations provide means to explore a synthesized, abstract representation of the network. Present simulations are primarily system-centric, used for understanding intractable systems, experimenting with new technologies and addressing design issues in the present network [44,45]. With the integration of QoS paradigms into the network fabric at the individual user level, simulation paradigms may also require a shift towards user-centric experimentation.

Simulation of core or distribution network may be used to address issues such as: How many VPNs can the core/distribution network support; when is it required to upgrade link/router capacities; is the router/link overloaded; how to shape the incoming/cross traffic at a node for quality compliance; When is it sufficient to enforce admission control and when is enhancement of network resources required. When interactive multimedia flows are supported over the internet, simulations may aid in assigning bandwidth to individual users and determining the number of such applications/users that can be supported. Present technology enables QoS compliant flow through resource reservation. In the near future, traffic engineering based upon MPLS technology may ensure QoS compliance. To effectively implement these technologies to provide adequate QoS, parameter such as bandwidth, link and buffer capacities, processing power required for packet classification/forwarding need to be selected. These parameters are specific to needs of the local network and typically exhibit temporal and spatial variability across the network. Simulations may provide a tractable means of tuning these parameters to demand patterns. At the end user level, simulation can aid in determining desired system behavior in response to changes in input traffic patterns and QoS requirements. At the system level simulation may aid in fine-tuning the network configuration parameters and verify compliance to SLA. These simulations may be carried out for C, D or E networks at different stages of the network life-cycle. Simulations may be used as a tool to facilitate capacity planning during network conception and design phase. After network deployment, simulations may aid in providing bottle-neck analysis to allow capacity enhancements and network flow reconfigurations. During the operational phase, simulations may also be used to provide guidelines for system tuning resulting in performance improvements.

5. GUARANTEEING QoS IN NEXT GENERATION NETWORKS

In section 2, following goals were identified for design of QoS compliant services in next generation networks: Eq. (1) Minimization of network response time yielding a small time interval between initiation of demand and allocation of resources Eq. (2) Dynamic load-balancing to absorb QoS fluctuations in the flow and utilize excess capacity distributed across different network nodes. The first goal facilitates effective implementation real-time applications and the second goal ensures scalability of the resource allocation scheme in presence of variability in the network conditions. It was pointed out that the non-stationarity of traffic pattern, asymmetrical bandwidth and heterogeneous QoS requirements preclude the use of static design approaches for next generation networks and an adaptive approach towards resource allocation may be necessary. In this section learning, prediction and correction model is proposed that may be integrated with CDE network to address dynamic resource allocation issues.

5.1 Methodology

For real-time applications, proactive design involving a-priori allocation of network resources based upon predicted demand may be a promising approach. This solution has two parts - demand prediction and resource allocation. There are several methods that can potentially be used for prediction. For example, hidden Markov models may be utilized for demand prediction using the first order dependency [55]. Linear or non-linear time-series models may be used [58,59] if higher order memory is a more appropriate representation of the system. For example, using a p^{th} order linear time series, the demand $D_i^{E_k}(t+\Delta t)$ can be estimated to be a function of demand in the past weighted by parameters α_k as

$$\hat{D}(t + \Delta t) = \sum_{k=0}^p \alpha_k D(t - k\Delta t) + \beta(t + \Delta t) \quad (6)$$

where, $\beta(t+\Delta t)$ is the noise in the model and can be modeled as a zero mean Gaussian distributed process. The superscript E_k is dropped in the above equation for brevity. The model order p and the coefficients α_k may be evaluated by fitting the model to an observed/measured time-series and can be assumed constant for a stationary stochastic process. However, the network traffic seldom exhibits stationary statistical behavior across geographical locations and time, as pointed out earlier. Therefore, the

choice of a single model and a fixed set of parameters cannot be universally assumed to represent the network characteristics accurately. Due to evolutionary nature of the network traffic, the models and its parameters may become obsolete requiring real-time selection of appropriate models and parameters. For example, a more appropriate model for network demand pattern may allow p and α in Eq.(6) to be functions of time. In addition to a mechanism for selection of an appropriate model, a "learning mechanism" that allows adaptation of the model with traffic may be required. Learning techniques such as hidden Markov models, artificial neural networks, genetic algorithms, or some regression methods could possibly be employed to learn the behavior [53-57]. The choice of genetic algorithms [53,54] is driven by its capability to simultaneously learn and predict the workload unlike other techniques such as artificial neural networks and hidden Markov models [55] that require separate training and operational phases.

5.2 Proposed Solution

Dynamic selection of model and an appropriate set of associated parameters require consideration of continuous variability in traffic and environment. We propose integration of network operations with online simulations as one of the promising methods for implementation of dynamic control. Fig. 2 shows the proposed architecture comprising of Workload Learning, Prediction and Correction (LPC) models integrated with online real-time simulations, both interacting with the operational CDE network. Learning, prediction, and correction model interacts with online simulation to arrive at an optimal parameter set using dynamic workload as an input. The adaptive workload model that describes demands placed by the input-requests on the various system resources need to learn the workload behavior of the system continuously in order to predict the future behavior. Based upon the expected behavior of the workload, simulation model may simulate the impact of several alternative configuration choices and an "optimal" parameter set may be chosen to configure the operational CDE network. The effect of changing the network parameters is collected in form of a feedback that is used as an input towards learning in LPC model. In the learning phase of the LPC model, the network feedback is utilized and prediction error and effectiveness of selected configuration parameters is evaluated. This information may be utilized in the simulation model to improve the simulation parameters/approach and strategy of parameter selection. In prediction model, the feedback from the learning model could be utilized

in selecting alternative prediction model or model parameters in successive simulation cycles.

The prediction, simulation and learning models are assumed implemented at each node in the CDE network. To be effective, these models should have the visibility of at least the immediate hierarchical neighbor. This would imply that the dynamic resource allocation strategy implemented in the core network should consider the impact of resulting delay, jitter, buffer occupancy and losses on the distribution network nodes. The selection of configuration parameters at the distribution network nodes should similarly consider the impact on the edge and core networks. At the edge network nodes, it may be sufficient to consider the impact of alternate resource allocation plan on the users and the distribution network nodes. Such an integrated approach can be used during capacity planning to determine the design parameters and expected network performance by replacing the actual real-time workload models by anticipated workload descriptions. During the network operational phase, simulations can assist in performing bottleneck analysis and network performance tuning using the real-time measurements.

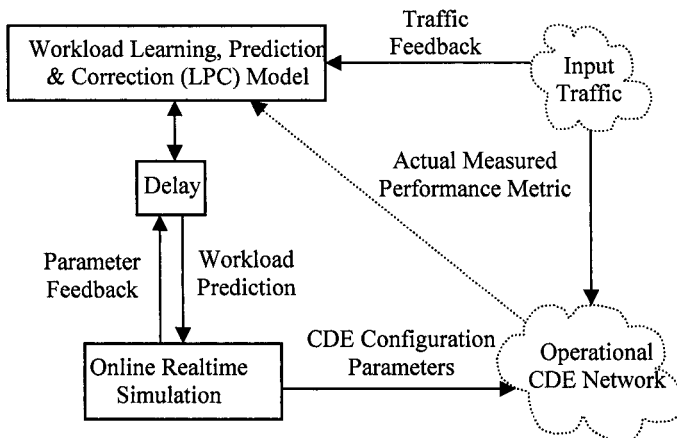


Fig. 2 Integrated Simulation and Operational Architecture for Next Generation Networks

5.3 Implementation Issues

Workload characterization and prediction has been of interest since 70s [49,50]. For typical batch or interactive systems used in 70s, static workload models were adequate to represent the user behavior. Dynamic workload models were introduced in 80s to represent variability in user

behavior followed by generative workload models in the recent years to bridge the gap between the user's application oriented view of the load and the actual load (physical, resource oriented requests) submitted to the system. Calzarossa *et.al.* [51, 52] provides a survey of workload characterization issues in standalone batch and interactive computer systems, database systems, communication networks and parallel distributed systems. For communication networks, layered approach of workload characterization is prevalent. An increasingly complex model for the network can be derived from combining workload descriptions of the participating processing nodes that in turn are described by combining the behavior of individual user inputs. The motivation behind workload models so far is to create an abstract, parametric representation of network load for artificial regeneration of traffic in simulation environments. Workload models facilitate *offline* performance studies without requiring actual measurements. The integrated LPC model proposed in this work requires a paradigm shift in simulation approaches that require *online* parameter estimation and learning. Implementation of the proposed architecture that integrates LPC workload model with CDE networks requires combining the workload measurement and modeling techniques with real-time services. The network traffic has exhibited variability in statistical behavior during different times of the day, with changes in constituent multiplexing flows and even at the granularity levels such as packets, blocks and user arrival patterns and traffic bursts. A mechanism for selection of appropriate workload model on-the-fly for each of these scenarios may be the next step. In the CDE hierarchy, bursty behavior of the traffic pattern may be expected to diminish in the network closest to the core network. Differences in traffic behavior across the CDE hierarchy warrants a careful selection of learning models that can best represent the evolving network features. Contemporary simulation approaches are primarily off-line and use static inputs. C, D and E networks are simulated separately with minimal or no mutual interaction. Steps in integrating these simulation approaches may be required to reinforce mutual learning for estimation and adaptation of optimal parameter selection.

6. CONCLUSIONS

Several challenges exist in supporting QoS compliant bursty real-time traffic in next generation networks. The primary challenge is provisioning resources within reasonable delay constraints. The resource reservation and allocation schemes are required that are scalable with non-stationarity

in traffic patterns, inhomogeneity in network conditions such as bandwidth, propagation environment and conflicts in QoS requirements. Workload learning, prediction and correction (LPC) model that takes the traffic as an input and continuously interacts with online simulation may be integrated with operational CDE networks. A-priori resource reservation using workload prediction is expected to address the timing constraints in the real-time traffic. Demand forecasts provided by predictive workload models are input to online simulation. Online simulation is envisaged to weigh several configuration choices and provide an optimal parameter set to accommodate the anticipated load. The scalability of reservation schemes is addressed through learning and correction approaches that utilize feedback from online simulation and network to update the simulation methods and prediction models.

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