A Framework for the Provision of Network Quality of Service for Enterprise Resource Planning Systems

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ABSTRACT

This paper presents research into the use of network Quality of Service (QoS) technologies to improve the performance of Enterprise Resource Planning (ERP) systems. The paper explores state-of-the-art QoS technologies and implementations and provides a framework for the provision of QoS for ERP systems that utilize Internet Protocol (IP) networks. Four individual case studies, including both leading ERP vendors and network technology vendors, were conducted. Cross-case analysis confirmed that the traditional approaches for ensuring the performance of ERP systems on IP networks do not address network congestion and latency effectively, nor do they offer guaranteed network service quality for ERP systems. Moreover, cross-case comparative data analysis also reviewed existing QoS implementations and suggested that while QoS is being acknowledged increasingly by enterprises as an important issue, its deployment remains limited. The proposed framework focuses on providing a structured approach to implement end-to-end IP QoS that accommodates both ERP systems and their Web-enabled versions, based on traffic classification mechanisms.

Keywords: enterprise resource planning (ERP) systems; IP-based networks; network quality of service (QoS) technologies

INTRODUCTION

According to Kumar and Hillegerberg (2000), ERP systems are configurable information systems packages that integrate information and information-based processes within and across functional areas in an organization. Other definitions may differ in their wording, but a common theme surfaces upon closer inspection: the integration of enterprise information.

Traditionally ERP systems have targeted the large, complex business organization, facilitating the integration and the
flow of information between functions within an enterprise in a consistently visible manner. Even with the current movement of repackaging the ERP systems for small to medium enterprises (SMEs) by ERP vendors, the governing concept remains: how can ERP systems support the integration of enterprise information across functional boundaries in an enterprise across geographical boundaries for multi-site enterprises, or even across organizational boundaries in order to reach external entities, such as suppliers and customers. It has been suggested that IS academics have been asleep at the wheel of the ERP phenomenon, and most of the early research has not examined the implications and complexities of enterprise-wide information integration (Kumar & Hillegerberg, 2000).

To support enterprise-wide information integration, the enterprise network infrastructure should be considered a critical component of the overall IT strategy and ERP system deployments. This is due largely to the fact that modern ERP systems have evolved from the centralized mainframe systems to the more scalable client-server architecture. The client-server ERP systems are distributed inherently and, therefore, are capable of supporting large, multi-site enterprises. However, the ERP client and the server communicate with each other mainly through network connections, and the quality of the network connections, therefore, has a very strong influence on the stability and performance of the entire ERP system.

The quality of the network traditionally has been measured mainly in terms of bandwidth. According to Delcroix and Green-Armytage (2002), between 1998 and 2003, Wide Area Network (WAN) bandwidth use in multi-national companies was driven by Internet applications and database applications, such as ERP. In the 2002-2003 period, bandwidth requirements were being driven by increased usage of these applications and by the growth of computer applications and graphical screen presentations.

Bandwidth, in general, is expected to become more of a commodity in the long term. In fact, enterprises already are enjoying the benefits of high-capacity Local Area Networks (LAN) at prices lower than ever before (Hiller, 2002). In the meantime, however, the WAN bandwidth price and the availability vary significantly from one location to another. Delcroix and Green-Armytage (2002) suggested that the long-distance markets offer sufficient bandwidth at acceptable prices in the United States and Western Europe. However, in less deregulated countries, bandwidth tends to be less available and hence more expensive. Enterprises constrained with IT budgets and local bandwidth availability will have to manage their network traffic effectively or face congestion on the enterprise networks. Globally, it has been predicted that some form of bandwidth management will be necessary during at least the next five-year period in order to bring bandwidth use in line with the acceptable cost for enterprises in various locations (Delcroix & Green-Armytage, 2002).

Furthermore, enterprises are experiencing heavy increases in bandwidth demand. A significant issue that leads enterprise network managers to doubt that the current enterprise networks will meet business requirements over the next two years is the continuing growth in volume of traffic. A study conducted by Ashton, Metzler & Associates and Sage Research (2001) showed that the vast majority of enterprises surveyed in the study has data traffic growing by 11% or more on an annual basis, and about a quarter of surveyed enterprises have data traffic growing by 51% on an
annual basis. Roughly one in 12 has data traffic doubling in a year or less. As the traffic volume continues to grow, enterprises are expected to increasingly encounter congestion-related problems, especially the enterprises that deploy multiple applications on the same network infrastructure. Nonetheless, there is an increasing number of converged enterprise networks that support all the enterprises' communication requirements. A large part of the network convergence movement can be attributed to the increasing popularity of Internet Protocol (IP) applications (Hafner, 2003; Pultz, 2001).

Network congestion in enterprise networks has traditionally been dealt with additional bandwidth (Ashton, Metzler & Associates, 2002; Delcroix & Green-Armytage, 2002, Melia, 1999). While this is considered as an intuitive, quick-and-easy way to alleviate the issue, the WAN bandwidth availability and cost of bandwidth often render this solution less attractive or, in some cases, impossible. Moreover, the inherent nature of the IP-based applications makes adding bandwidth less effective in dealing with network congestion, as some applications tend in the long term to consume all of the available bandwidth on the network, regardless of how much bandwidth there is. These bandwidth-hungry applications are typically applications such as Web applications, e-mail, and File Transfer Protocols (FTPs). While the importance of an application is highly dependent on the business activities and goals of the organization, these applications generally are considered less important to enterprises. When these applications happen to consume most, if not all, of the available resources on the network, other applications, such as ERP systems or VoIP, suffer and perform at suboptimal levels.

In addition to bandwidth, enterprises also must take into account the latency or response time required by applications and end users. When networks become saturated, latency increases. Historically, latency problems encountered also have been tackled by upgrading the network bandwidth capacity. However, previous literature also has suggested that the strategy of adding more bandwidth is ineffective by itself to deal with latency problems (Adams & Bawany, 2002; Cisco Systems, 2001).

Over the last few years, both academics and practitioners in the field of network management have searched for an alternative or a complementary strategy to network bandwidth. The result is what has been termed Quality of Service (QoS). QoS is a relatively new technology that primarily has been shaped by the practitioners, including numerous Internet technology workgroups and key network technology vendors. QoS is considered a general term referring to the technologies that classify network traffic and then ensure that some of that traffic receives special handling (Armitage, 2000a; Huston, 2000; Siegel, 2000). QoS in theory allows an enterprise to efficiently utilize the existing network resources by providing tools for managing a set of parameters, including bandwidth and latency, for an arbitrary amount of network traffic. This can be desirable where a single network infrastructure supports a multitude of applications.

QoS can be a compelling alternative to sheer bandwidth, because it has the potential to be more cost-effective and to provide more control on the network. QoS as a subject has a diffuse body of literature. In the academic world, the various techniques and architectures of QoS are well understood. However, most of the studies to date have not examined in detail the com-
plexity and the implications of implementing QoS on a converged network for data applications. While numerous studies on implementation of QoS for voice applications over IP networks have been carried out and published, such as in Fineberg (2002) and Siegel (2000), very little is known about the network requirements of today’s ERP systems and how QoS technologies can be deployed to satisfy these requirements.

In theory, ERP systems should make great targets for network QoS. As with most client-server applications, network quality heavily impacts the performance and the stability of the entire ERP system. ERP systems generally are regarded as mission-critical to most enterprises; hence, it would be legitimate to provide preferential treatment in times of network congestion for ERP traffic. Moreover, the inherent nature of ERP systems and their typical deployment in a business environment implies that the cost and availability of WAN bandwidth are potentially limiting factors in system deployment and performance. Therefore, research into how QoS technologies have been or can be used for ERP systems should be of high priority, but it is not.

Moreover, numerous papers and articles that appeared in influential trade press publications and IS journals by authors such as Anderson (2001), Scheer and Haberman (2000), and Comport (2001), suggested that ERP, like many other mission-critical enterprise applications, is in the process of a makeover. Gartner Research coined the term ERP II and suggested that ERP II puts an outward focus on ERP. This is expected, at least technically, to involve a fast move toward Web-based systems. The push behind this movement comes from the widespread use of the Internet. Rao (2000a) pointed out that, with the arrival of the Internet, the biggest challenge facing ERP suppliers is to address the global access issues that would cater effectively to intra-organizational and extra-organizational needs. Anderson (2001) suggested that the way most ERP vendors address these issues is by utilizing native Internet technologies and network infrastructures. However, today’s Internet is based largely on best-effort IP networks, and its technologies, such as HTTP and HTML, were not developed to offer mechanisms for ensuring the performance of applications that use them. QoS, therefore, is potentially valuable for Web-based ERP applications. The current literature, however, has limited coverage regarding the methods, implications, and complexity involved in providing network QoS for Web-based applications.

Furthermore, the market for enterprise networks always has been characterized by innovations and rapid advancement of technologies. The latest advancements in traffic classification, such as Layer 7, are potentially valuable enhancements to current QoS technologies, as traffic flows must be identified to allow differentiated treatment. However, Layer 7 traffic classification is a relatively new concept and has not been tested and adopted widely. A framework to explore the potential of this technology for the provision of QoS for applications such as ERP systems does not exist in the current literature.

In summary, the gaps within the present literature related to network QoS and ERP systems identified here have limited the practicality of QoS implementations for ERP systems. Moreover, an array of interrelated marketing and technical trends highlights the importance of this research, including the following:

- ERP systems are increasingly being deployed on IP networks.
- The movement toward converged networks is observable among enterprises.
WAN bandwidth cost and availability vary significantly.
IP networks largely remain best-effort networks.
The growth of traffic on enterprise networks is saturating existing networks.
The maturing QoS technologies and advancements of traffic classification technologies.
The arrival of the Internet era and the evolution of ERP systems.

The overarching purpose of this paper, therefore, is to explore the ways QoS can be implemented for ERP systems that utilize IP networks and then to use the results as a guide to develop a framework for the provision of QoS for ERP systems.

RESEARCH OBJECTIVES AND QUESTIONS
The first objective is to explore and identify the reasons to provide network QoS for ERP systems that utilize IP networks. To achieve this objective, the research must answer the following question:

*RQ 1: Why is it necessary to provide network QoS for ERP systems?*

The second research objective is to explore how QoS is currently implemented on IP networks that support ERP systems. As revealed through reviewing the existing literature on network QoS, a wide array of QoS technologies and mechanisms is available. This allows network managers and system implementers to be selective and to implement the technologies that are most appropriate for providing network QoS to ERP systems. The deployment of these technologies is likely to depend on a number of factors, including ease of deployment, scalability, and the organizational context. The second research objective is defined to provide insights into the following research questions:

*RQ 2: What are the available QoS technologies that can be implemented to provide end-to-end network QoS for ERP systems?*

*RQ 3: What is the current status of deployment and common deployment topologies of the available QoS technologies to provide end-to-end network QoS for ERP systems?*

While for the first and the second research objectives a sequential relationship does not exist, it is envisioned that the completion of research objectives one and two is required to achieve the third research objective. Based on the knowledge acquired from the first and second objectives, the final objective of the research is to propose a framework for the provision of network QoS for ERP systems that utilize IP networks.

RESEARCH METHODOLOGY OVERVIEW
With a diffuse body of literature on network QoS and the largely exploratory nature of the research questions, qualitative research methodologies were the preferred choice from the outset. Moreover, the specific markets related to this research are characterized by oligopolic vendors dominating the market. This research would have to embrace technical and organizational issues as well as the current trends in these markets and, therefore, needed to focus on a small number of leading vendors rather than a large number of smaller second-tier vendors. For this reason, a case study research methodology seemed to be more appropriate than survey techniques.
The interpretive nature of the research suggested the use of a methodology that is capable of and focused on gaining a deeper understanding into the phenomenon under study. In this case, the scope of the research method must be able to include technological as well as organizational and behavioral factors and relationships related to the ERP systems and QoS. Moreover, interpretive research usually is conducted in order to understand phenomena in the context of situations. The authors felt that quantitative research methods, including experiments and surveys, do not offer the required realism for this kind of research. Benbasat, Goldstein, and Mead (1987), however, suggested that a case study methodology might be better suited in the context of this type of research. IS is characterized by constant technological change and innovations. IS researchers, therefore, often find themselves trailing behind practitioners, which is true particularly in the disciplines of ERP and computer networking. It has been suggested that researchers often learn by studying the innovations put in place by practitioners. These factors also helped to persuade the authors that, for this research, the case study might be the best-suited research method to capture the knowledge of the practitioners.

For this research, the authors selected a holistic, multiple-case design (Yin, 1994). The unit of analysis has been determined to be organizations, which is expected to allow the research to acquire most effectively the information needed for answering the specific research questions. The target population has been defined to include leading vendors in the markets of ERP applications and network technologies. The market status of each identified vendor was assessed using metrics such as market share and size of its installed base, based on information published by third-party organizations and general word-of-mouth. Four organizations eventually were selected to be included in this research. Eight face-to-face and three e-mail interviews were used to collect data. The interviews produced about 150 pages of transcripts. Additionally the authors used approximately 1,800 pages of secondary data (company reports, white papers, Web site information, etc.). The e-mail interviews were based on the framework provided by Chadwick (1996) for collecting case study information via the Internet. The data analysis strategy that was been custom-built for this research focused on the identification of common patterns or themes among the cases through the use of data reduction and display methods in Huberman and Miles (1998), within-case analysis, and cross-case comparative analysis methods suggested in Eisenhardt (1989).

According to Alter (1996), information systems can have three different dimensions: organizational, technical, and managerial. For the research objects of this work (ERP systems and network QoS), the three dimensions were identified and adapted as follows:

- The organizational or vendor dimension
- The technology dimension
- The market dimension

The three dimensions were used effectively in the categorization of case data, which allowed a reduced set of case data to be presented for each dimension. Cross-case comparative analysis was conducted for the three dimensions with the aim of identifying patterns that were relevant to the issues informed by research questions. Tables were used as the primary presentation tools for reduced data sets and identified patterns. The cross-case patterns were
used to answer the specific questions of the research — RQ 1, RQ 2, and RQ 3.

CASE STUDIES: NETWORK VENDORS

The primary source of data was semi-structured, face-to-face interviews with key vendor engineers and consultants. However, a significant portion of the case study data came from a number of secondary sources, including articles and books published by the companies, internal training documents, product documentation, downloaded Web material, and archival records.

Company A

Company A, although headquartered in the US, has offices in more than 50 countries and employs more than 35,000 people around the world. The company’s strategy is to be prominent in advancing the development of IP, which it considers to be the basic protocol of the Internet and private networks. The company aims to position itself as innovative, a technology leader, and pushing everything into the network. According to industry researchers (citation excluded due to confidentiality agreement), Company A has 50% to 90% market share in the enterprise network markets, depending on the product category. Company A offers a broad line of network solutions for LAN, MAN, WAN, optical, and wireless networks.

Company A’s hardware product lines, such as hubs, switches, routers and access servers, are the basic building blocks to its network solutions for small, medium, and large networks. Within each product line, Company A offers a number of product series, each differing in terms of price, performance, and functionality, and targeted to support different types of networks. In particular, Company A has an extensive range of routers and switches; both product lines have more than 20 product series and combine to give more than 100 product models. A number of Company A’s flagship routers and switches families are managed by a proprietarily developed operating system software that provides a common interface across the hardware platforms. The operating system has been regarded as an important software solution that performs a number of critical functions, including routing and switching, network management, security, MPLS tunneling, multi-casting, support for voice and video applications, and Quality of Service (QoS).

This case provides a detailed description of company A, its perspective on network QoS, its QoS tools, and its recommended network solutions and QoS implementations for ERP systems. Due to the space limitations of this paper, the authors present just a summary of the cases. Full details of the four case studies, including interview quotations, reference to source documents, diagrams, and so forth can be found in Lo (2002).

Company A, while in an active effort to push its QoS solutions to its customers, also recognizes the importance of upgrading the network capacity. However, there are certain classes of enterprise applications that require more than sheer bandwidth in order to perform satisfactorily on a converged IP network. These applications include voice, video, and ERP systems. Company A considers QoS critical to ensure ERP system performance, particularly over the WAN links, and provides a comprehensive set of per-hop QoS mechanisms and full support for the various QoS network models to deliver end-to-end QoS for ERP network traffic.

The specific approach of Company A toward implementing QoS for ERP sys-
tems is described in the case. In general, network traffic usually is classified and prioritized using Layer 2-4 header information. The class-based prioritization then is honored throughout the network, using multi-queue congestion management techniques, WRED for congestion avoidance, and traffic shaping based on token-bucket metering. These per-hop QoS mechanisms usually are coordinated by DiffServ or IP Precedence, as Company A considers IntServ inappropriate for ERP traffic, given its specific traffic patterns.

**Company B**

Company B, founded in 1996 in the US, is a network technology vendor in the enterprise and service provider network markets that specializes in the provision of Quality of Service (QoS) for networked applications and managed services. Company B received net revenue of $46.6 million for the 2001 fiscal year. It currently employs approximately 200 employees, and its products are sold by more than 100 resellers, distributors, and system integrators in more than 50 countries. The products and service provided, according to Company B, are designed to enable enterprise and service providers to measure, control, and validate the performance of networked applications. It is considered a dominant player in that particular market niche. Its products, according to Company B, are being deployed worldwide. Current statistics show that more than 18,000 units of the company’s flagship product have been shipped worldwide to date (Company B, 2002f).

Company B considers QoS necessary for enterprise applications, such as ERP, VoIP, and real-time video. Over-provision of the network in its pure form is seen as a short-term solution to issues arisen from network resource contention on best-effort networks. Moreover, Company B also recognizes the need to provide preferential treatment for certain classes of Web traffic, whereas Web traffic, in general, has been treated as secondary in terms of its importance to the enterprise. In the view of Company B and its consultants, Layer 7 classification is critical to effective implementations of QoS for ERP systems on modern networks.

The patented QoS technology played an important role in defining the concept of QoS for the company. With TCP rate control, bandwidth and network delay becomes the major parameter for defining QoS for Company B, since TCP rate control in theory eliminates queuing and loss of packets due to router queuing management and policing. The QoS implementation, as recommended by Company B, also is discussed in the case study, which emphasizes the provision of QoS for network connections that tend to span LANs and WANs.

**CASE STUDIES: ERP VENDORS**

The first section of each case study contains a brief overview of the company, which is followed by a description of the company’s flagship ERP systems, focusing on issues that center on system architecture, network traffic patterns, and requirements. The case study then proceeds to explore the approaches of the vendors toward network performance issues, QoS concepts, and technologies.

**Company C**

Company C was founded in the late 1970s in the US. It has been among the leading vendors in the ERP market worldwide; it received annual revenue of $894 million in 2001 and currently has approxi-
mately 6,500 mid-market and large customers with sites in more than 100 countries. To support this scale of operation, Company C employs close to 5,000 people in 18 US offices and 60 international offices. Company C also has more than 300 partners, from consulting firms to small organizations, that provide service to customers in remote locations (Company C, 2002c, 2002d). Company C offers a wide range of software solutions, including ERP systems, Supply Chain Management (SCM) systems, Customer Relationship Management (CRM) systems, and various collaboration tools.

The company’s first ERP product was named C0 and released in the late 1980s. At the time that it was released, C0 was not designed to be implemented in a distributed environment. According to Company C, C0 uses a monolithic, or host-centric, system architecture. Its successor, released in the mid-1990s, was named C1, which has since become Company C’s flagship ERP system.

Recent statistics show that there are approximately 1,700 customers worldwide that are live on C1 (Company C, 2002a). One of the major differences between C1 and C0 is an architecturally defined one — C1 was designed to be a platform-independent, distributed, client-server system in order to provide both performance and scalability over the underlying network infrastructure.

While single to multi-tier implementations are possible, the most common implementation of C1 has been the three-tiered architecture. The client tier supports a traditional fat-client configuration, using the proprietary Win32 client executables, storing C1 logic and static data elements. The Win32 client has C1-specific middleware and APIs to handle the message-based communication between application elements and servers. Other supported clients include Web-based clients, using a Web server, and server-based technologies, such as Windows Terminal Service and Citrix MetaFrame.

The server tiers include the application servers, database servers, and, for Web-based clients, Web servers. The Enterprise server is the term given to the server that hosts both the application functions and the database functions. When C1 users choose to implement the Enterprise server, the system architecture is termed the virtual, or logical three-tiered architecture. While the Enterprise server approach has its pros and cons when compared to the physical three-tiered architecture, they do not directly relate to the use of network resources.

Company C, as well as its customers in general, have moved away from the traditional Win32 client to the fully Web-enabled ERP solution. According to Company C, this approach has made it possible to reduce the volume of traffic being injected into the network by their ERP systems. However, Company C and its ERP systems currently do not provide QoS at the application. The typical recommendations from the consultants at Company C focus on bandwidth upgrades.

The increasing adoption of the Web-enabled C1 system implies a new set of traffic characteristics and requirements that Company C and its clients must take into consideration during various stages of ERP implementation and operation. Some of the major considerations include the use of HTTP and HTTP-S protocols over WAN networks, encapsulated print data, and multi-media object attachments.

Company D
Company D was founded in the early 1970s in Europe and has since grown to be
the world’s leading software vendor in the ERP market with a market share of about 36%. Company D currently has an installed base of 44,500, serving approximately 10 million users at 17,500 organizations in 120 countries. Company D currently employs approximately 28,000 people in more than 50 countries. The reported annual revenue for Company D for 2001 was 7340.8 Euros million. Company D offers the broadest ERP functionality among its competitors, providing solutions to more than 20 industries, including both manufacturing and services. These solutions incorporate the so-called best practice for conducting businesses in these industries. In recent years Company D has been committed to the development and implementation of functionalities, such as SCM, CRM, and database warehousing.

The two predecessors of Company D’s flagship ERP system, D1 and D2, were released in the 1970s. Both D1 and D2 were developed to satisfy the business needs of mainframe users. D2 became the major product of Company D in the 1980s, when the centralized computing paradigm prevailed. D3 is the logical evolution of the D2 system and the product that actually has fueled the expansion of Company D since its introduction in the early 1990s (Company D, 1999a).

D3 is a real-time, client-server software solution, whose functionalities are based on the concept of business processes. D3, since its initial release, has undergone a series of expansions in functionality and technology enhancements. The version of D3 released in 1996 was Internet-enabled through the use of open, Web-based technologies such as Java, Web browsers, and Web servers. The next major release of D3, while maintaining the commitment to open technologies, focused on achieving fast implementation of componentized D3 systems.

The D3 system, from a software perspective, is structured in a three-tiered, client-server architecture, with each tier having a distinct function. Conceptually, all data are stored in a database and processed in the application layer on the application servers. The client programs, or the presentation layer, are the interface to the user. All three layers communicate with each other through the network. Physically, the three-tiered architecture has been the most common implementation. It is possible, however, to implement D3 with a single to N-tiered architecture. Moreover, with the introduction of HTML clients, D3 systems now are considered to be structured in a multi-tiered architecture (Company D, 2002a, 2001d, 2001e).

There are three types of D3 client programs: Win32, Java, and HTML. The Win32 client is the best-known client program for D3. The advantage of the Win32 client is its singular range of functions. The Java client can be implemented on most known platforms. The HTML client uses a pre-installed Web browser to show the application and data.

While each network connection supported by D3 has its own set of requirements that must be satisfied by the supporting network infrastructure, which is derived from both the business requirements of the enterprise and the technical requirements of the D3 system and communication protocols, the network requirements of D3 network connections have been described in general as qualitative.

Due to its distributed nature, all the tiers of the D3 system are connected by networks, usually TCP/IP. This paper, adhering to Company D’s conventions, roughly divided the network connections into two categories, based on the type of supporting network infrastructure. Server
communication, which includes connections between the servers that are usually supported by LANs, is considered vital to D3 system performance. To ensure that the supporting LANs fulfill the stringent network requirements of server communication, Company D strongly recommends D3 users to take advantage of low-cost LAN bandwidth. For this reason, experience suggests that the LAN connections very rarely become performance bottlenecks of D3 systems. The access communication, however, can become the focal point for network performance tuning when network connections span LANs as well as WANs. This is especially the case for Web-enabled D3 systems.

Other than the continuous effort to reduce and control network load created by D3 systems, Company D recently has QoS-enabled its flagship ERP system by providing software support for RSVP. Nonetheless, QoS, through resource reservation, has yet to find its way to current D3 implementations. Most D3 consultants and D3 partner consultants remain supporters of the over-provisioning approach for issues such as network congestion and long response time.

CROSS-CASE ANALYSIS

This section contains the cross-case analysis of the case studies. The following discussion focuses on answering questions posed by the first two objectives of the research.

The cases were comprised of contrasting organizational values, business practices, and technology adoption. The selection and number of cases allowed a rich, representative description of the research domain and provided an opportunity to establish external validity. Within each case, an array of selected issues was discussed extensively. These issues, which are referred to as the focal issues throughout this section, include the following:

- ERP systems and the supporting network infrastructure
- ERP traffic profiles
- Perspective toward QoS
- QoS tools available
- QoS implementations for ERP systems
- Current implementations to ensure ERP performance on the network

Three dimensions — vendor, market, and technology — are used for comparative analysis and pattern clarification across the cases.

The vendor dimension provides a description of the issues centered on the values, speculations, preferences, and strategies of the vendors described in each individual case study. The vendor dimension provides a valuable insight into the research problem, as these vendors, with their large installed base and commanding share in their respective markets, are expected to have the ability to shape the current and future markets relevant to this research. Across the cases, the first and foremost pattern that can be observed is the clear separation of duty between the ERP vendor and the network technology vendor. The ERP vendors effectively considered themselves providers of enterprise application software; while they provide consultancy services and guidelines for hardware sizing during the ERP system implementation, they usually do not participate actively in the design and implementation of the underlying network infrastructure. The focus of the ERP vendors has been to develop software solutions that are highly extendable, configurable, and can be implemented within a reasonable timeframe. The hard-
ware requirements of the ERP systems, including servers and network infrastructure, are passed on to the hardware vendors, who, in turn, are expected to design and deliver the necessary hardware infrastructure.

The ERP and network technology vendors, following their own visions and missions, have specialized in the areas in which their expertise and competences lay. This specialization provides a strong business case for the common separation of duties in ERP system deployments.

The technology dimension adds another layer of detail that is focused on providing an in-depth, technical description to the focal issues of this research. The technology dimension is fabricated mostly from hard, quantitative data elements from the cases studies. The market dimension adds the third and final layer of detail, which is focused on providing a description of markets trends, as observed by the ERP and network technology vendors, regarding the focal issues identified previously. The market dimension is fabricated mostly from interviewee experiences in providing products and services to their respective client enterprises.

Analysis of Cross-Case Patterns

The patterns or themes identified provide valuable insights into the main research issues. The specialization or separation of duties in a typical ERP system implementation appeared to be the grand pattern underlying many of the themes identified. For instance, the network technology vendors generally support network QoS, while the ERP vendors continue to be committed to the approach of having over-powered networks and running ERP systems that have been optimized in terms of bandwidth requirements. Moreover, network technology vendors generally have a high level of understanding of the network requirements for a typical ERP system. However, this understanding is limited somehow to the earlier versions of the ERP systems — versions not enabled for Web-browser access.

This observable specialization, however, does not appear to completely isolate the two types of vendors from each other. It can be expected that, as long as their targeted markets intersect with each other, ERP vendors likely will be aware of technologies offered by the network technology vendors and vice versa. The likelihood of any one side devoting an extra effort to better understand and utilize the technologies offered by the other, such as Company D enabling D3 to support traffic identification and RSVP signaling, is likely to depend on a series of interrelated factors. For ERP vendors, the factors include the value of network QoS as perceived by the company and its consultants in comparison with bandwidth cost, the attitudes of other ERP vendors, and ultimately the level of demand for QoS from potential customers. As for the network technology vendors, the single most important factor is likely to be the perceived demand for QoS from organizations deploying or running ERP systems.

ACHIEVING THE RESEARCH OBJECTIVES

The case study data analysis and the literature both suggested that the necessity to provide network QoS for ERP systems ultimately arises from the mission criticality of ERP systems and their dependence on the underlying network infrastructure, and that they are under the influence of the combined effect of organizational, market, and technology factors. Those factors include the following:

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The Internet revolution.

The increasing ubiquity of IP networks and several contemporary trends associated with IP, including growth of network traffic and demand for IP bandwidth, network convergence, IP bandwidth cost, and availability.

The evolution of ERP networks.

Figure 1 illustrates the case for Research Objective One diagrammatically. The unshaded area includes the factors and relationships (represented as arrows) that have been suggested in the existing literature. The shaded area, on the other hand, includes additional factors and relationships that are identified and presented in this paper. The factors and relationships that are included in the shaded areas are considered additions to the existing literature in the sense that they have not been studied from the perspective of this research; for instance, the Web-computing paradigm and the evolution of ERP systems may have been studied well for purposes other than to provide network QoS for ERP systems. Therefore, these factors and relationships are the center of discussion here.

Generally, the mission criticality of any enterprise application depends mostly on the organizational context. However, modern ERP systems, unlike any other enterprise applications, have been deployed and used in such a way that the continuation of the business operation relies on ERP systems to perform at the level that is required by its users. The performance of any ERP system is measured, in turn, against what it is designed to achieve.

It is clear that, due to its mission criticality, ERP systems need to perform at the level defined by the system users with regard to the requirements discussed previously. Additionally, the current literature suggests that modern ERP systems depend heavily on the underlying network infrastructure for meeting its goals as a mission-critical system. The reliance on the network infrastructure to provide the nec-
Essential connectivity for system access has been growing continuously; as MRP evolved into MRP II and from MRP II to current ERP systems, its deployments have become more and more distributed due to the changing business environment and the increasing prevalence of the client-server paradigm.

The current ERP systems, from the functional perspective, are developed to support multi-tier implementations. Most enterprises have implemented three-tiered ERP systems and rely on the TCP/IP network’s infrastructure to provide the connectivity required for interactions that occur between-tier, within-tier and between-ERP systems. The literature on ERP evolution, as well as the observable trend toward Web-based computing in the case studies, provided evidence that modern ERP systems should be viewed as networked enterprise applications. As the dependency on the underlying network infrastructure grows, the abilities of ERP systems to perform at the level defined by system users increasingly are related to the quality of the underlying network infrastructure.

The ERP vendors, enterprises, and network technology vendors have gone to great lengths to ensure the quality of the network. They use network sizing guidelines for designing and implementing the networks for ERP systems that are expected to fulfill the pre-determined capacity, availability, and scalability. Common methods that have been used for reducing the likelihood of network-induced performance bottlenecks include the use of dedicated network paths for ERP communications, network over-provisioning, and minimization of per-user/transactional network requirements at the application/network level, using technologies such as data caching and compression, file transformation, Web-based computing (as in C1), and proprietary optimizing protocols for data transmission, such as the protocols used in D3. The ERP implementation and maintenance strategies adopted by most enterprises, as revealed by the interviewees, are to use some combination of these methods. For instance, when an enterprise deploys its chosen ERP application suite, the deployment likely is to utilize at least part of the existing enterprise network. Depending on the organizational context, the enterprise may or may not implement separate networks for newly deployed ERP systems. However, regardless of the implementation decision (new or existing, converged, or separate network infrastructure), the conventional wisdom has been to equip the underlying network infrastructure with more than sufficient transmission and processing capacity to facilitate the overall average communication needs for the entire enterprise, thereby providing a safety net that increases the likelihood of consistent ERP performance. Data compression and caching, file transformation, and other transmission-optimizing techniques also can be installed and configured during the implementation and maintenance stages. The post-implementation strategy for alleviating network performance bottlenecks due to the natural growth of enterprise network traffic, including the components of organizational growth and the general trend of enterprise application development, has been to continuously add more bandwidth.

The literature review and the individual cases studies, however, revealed that these network-related, performance-ensuring methods have numerous inherent characteristics/weaknesses that limit their effectiveness in guaranteeing the level of performance dictated by the mission criticality of ERP systems. These findings highlight the fact that currently the most common implementations for ensuring ERP
systems performance on the enterprise network are imprecise approaches in terms of satisfying one of the most important requirements of modern ERP systems and their enterprises users — they are unable to recognize network connections of ERP systems and provide controllable, guaranteed network service quality for these connections. The fact that the parameters of service quality (i.e., bandwidth, latency, jitter, and packet loss) of the networks supporting ERP systems cannot be controlled and guaranteed implies the enterprise risks’ suboptimal ERP system performance with regard to key user requirements. Given the current dominance of best-effort IP networks and the persistent scarcity of WAN bandwidth, the probability of network ERP systems performing at the less-than-satisfactory level cannot be overlooked. This study’s findings also support this speculation. QoS technologies, on the other hand, have been developed with the specific purpose to address the limitations of IP networks, which appeared to be root of the weaknesses of the traditional implementations to ensure ERP performance on the network. The advantage of QoS over over-provisioning and separate network paths, for instance, increasingly is being recognized by business enterprises and practitioners. Fundamentally, QoS technologies first allow the enterprise users to control the various service quality parameters and to enforce such controls end-to-end for all network connections that deserve differentiated service. Second, the financial costs of QoS technology usually are the cost of infrastructure that tends to be a one-off expenditure. Over-provisioning converged/multiple network infrastructures, however, often are associated with both infrastructure cost and the increased, ongoing subscription cost for WAN connections.

In summary, it is proposed here that it is necessary to provide network QoS for ERP systems, due to the combined effects of numerous organizational, market-oriented, and technological trends. The fact that ERP systems currently are deployed and used in such a way that the enterprise needs to guarantee the end-to-end service quality of the underlying network in order to ensure optimized system performance implies that network QoS is needed for ERP systems, since IP networks, as well as the current implementations aimed to ensure ERP performance, do not offer the mechanisms required to control and guarantee network service quality. Contemporary trends in the markets of ERP systems and IP networks (i.e., market globalization, IP ubiquity, network convergence, the Internet revolution, and ERP’s evolution) also amplified the necessity of network QoS for ERP systems. The organizational context can be another major reason that QoS is needed for ERP systems; for instance, modern ERP systems are increasingly being deployed by SMEs around the world. The sheer cost of bandwidth and/or the cost of maintaining multiple network paths to ensure ERP system performance may not be a viable option for many of those SMEs.

Achieving Research Objective Two

The literature review suggested that QoS is a rapidly growing discipline; however, the use of ambiguous terms has opened a schism between the networking industry and academia’s understanding of QoS issues. The cross-case analysis presented previously supported this suggestion. For instance, out of the three network technology vendors that offer mechanisms to achieve network QoS, at least two major kinds of QoS tools are identified: First, QoS tools that concentrate on utilizing the intrinsic abilities of modern routers switches
to provide per-hop QoS and enforce end-to-end QoS through various QoS network architectures appeared to be the most common implementation of the QoS tools available today for two reasons:

- **Classification, marking, queuing, and scheduling** are the basic functions of modern routers or switches. It is then logical to utilize these basic functions and to further enhance them, if necessary, to achieve per-hop QoS. According to the interviewees, most modern routers/switches offer basic QoS functions, including Layer 2-4 traffic classification, congestion management, multi-queue management, and QoS-enabled scheduling. This implies that in order to enable per-hop QoS, little infrastructural cost and implementation efforts are involved in most cases. Moreover, rapid advancing hardware implementations of classification, queuing, scheduling, and switching using technologies such as ASICs have increased the performance of routers and switches by several orders of magnitude.

- **Numerous network QoS architectures**, including IEEE 802.1 Q/D (CoS), IntServ, DiffServ, and MPLS, and the related service models, including GF and CL of IntServ, AF, and EF for DiffServ, have been standardized by the relevant IETF working groups. The standardization of these network architectures and service models fueled greater interoperability among the QoS tools offered by different network technology vendors. Moreover, existing and emerging research on topics, including QoS mappings across different layers of the OSI model and internetworking of various network layer QoS protocols (Fineberg, 2002; Le Faucheur et al., 2002) allowed network professionals to capitalize on the strengths of various network architectures in order to develop an end-to-end, QoS-enabled network.

The other approach, which focuses on achieving network QoS through the manipulation of the TCP/IP sliding window protocol, also has become a recognized technology. Due to the fundamental philosophies of TCP rate control, its effectiveness relies largely on the abilities to pace the packets so that the predetermined bandwidth and latency requirements are met. Moreover, the fact that the TCP rate control intercepts and manipulates the ACK messages appeared to violate one of the original design goals of TCP. Many users, however, have suggested that TCP rate control is an effective tool to control and enforce application-level QoS policies (Ashton, Metzler & Associates, 2002).

One of the most important findings from the case studies is the usage and importance of Layer 7 traffic classification technologies in the provision of network QoS. As indicated by the limited literature on traffic classification that uses Layers 4 through 7 packet information, such technologies only have emerged recently, and their adoption remains limited. Moreover, it also has been suggested that the implementations of Layers 4 through 7 classifications are usually vendor-specific. The case studies, in fact, showed two different implementations of Layer 7 classifications and provided insights into their intended usage. While the implementation of Layers 4 through 7 classifications may differ technically (i.e., the hardware implementation, classifier architecture, and classification algorithms typically differ from vendor to vendor), the case studies suggested that, for the provision of network QoS, soft-
ware-based classifiers appeared to be the main approach among network technology vendors. According to the interviewed practitioners, the software-based traffic classification provided the highest flexibility, including subapplication classification by variable text strings, multi-media object types, and user host information. This ability to achieve subapplication traffic classification can be a considerable advantage for complex networked enterprise applications, such as ERP systems that are supported by best-effort IP networks.

The case studies also revealed an alternative to achieve subapplication traffic classification. Instead of parsing and/or scanning the packets for the occurrence of predefined strings or objects, a new class of enterprise application allows its users to identify the subapplications network connections by utilizing host-based QoS functionalities.

Network QoS, in general, has not yet been widely deployed. The existing literature as well as the case study data suggested that QoS-enabled networks constitute only a fraction of existing IP networks. The main drivers for existing and foreseeable future QoS deployments have been to provide guaranteed, preferential services for the following enterprise applications:

- Real-time, streaming audio and video, including VoIP and video conferencing applications
- Highly interactive thin-client applications, including applications published in Citrix and/or Windows
- Terminal service environments. Mission-critical, interactive applications such as ERP systems

ERP systems, however, increasingly are being considered as top candidates for QoS by various organizations that use or are planning to deploy ERP systems. According to the interviewees, ERP systems are the number-one QoS candidate among data applications, largely due to its mission criticality and to their dependence on the supporting network infrastructure. However, early adopters of QoS to provide preferential services for ERP systems on IP networks also are confronted with numerous difficulties, including the following:

- Determining the traffic profile and requirements of ERP systems on the network for optimized system performance
- The technical complexity of QoS installations and configuration

Voice and video applications are known to have consistent performance requirements that need to be enforced somehow across the enterprise networks. ERP systems, on the other hand, as with most networked data applications, have qualitative network performance requirements, which implied additional complexity in QoS provision for ERP systems, as the associated network requirements tend to vary in different environments and must be profiled prior to the implementation of QoS. In fact, the case study data showed that the complexity of QoS implementations and cost of bandwidth often are decisive factors in the adoption of QoS for ERP systems.

The case data suggested that the widespread adoption of these technologies can be expected when enterprises, in general, become more familiar with QoS technology and the complexities associated with providing qualitative QoS. Moreover, as QoS technologies evolve over time, the network technology vendors are expected to be increasingly capable of quantifying
Achieving Research Objective Three

The motivation of research objective three arose from the fact that the review of existing literature on network QoS suggested a general lack of practicality in terms of actual implementation for networked data. The proposed framework aims to provide a set of practical guidelines to implement end-to-end IP QoS for ERP systems, which is expected to allow a more structured implementation process.

The Proposed Framework

It was expected that the achievement of research objective one and two would provide the fundamental architecture blueprint to propose the first framework for the provision of network QoS for ERP systems. Upon close scrutiny, the answers to RQ1, RQ2, and RQ3 have led the proposed framework to focus on the following issues:

- For ERP systems, it appeared that it would be most cost-effective to provide subapplication QoS so that each ERP network connection receives the service quality it deserves.
- The provision of QoS must be extended to cover the entire spectrum of ERP deployments, ranging from Win32 clients to HTML clients deployments.

Focusing on these issues, the proposed framework contains three major components: ERP profiling, evaluation of alternatives, and the implementation of an end-to-end, QoS-enabled network infrastructure.

**ERP Profiling**

As with most networked applications with qualitative network requirements, the requirements of the network connections supported by ERP systems are variables that depend on factors such as user expectations, applications, transactions, and time. Therefore, an effective QoS implementation for ERP systems must be based upon an accurate, up-to-date traffic profile of the planned or existing ERP deployment.

Due to the mission criticality of ERP deployments, there are several reasons to believe that a formal, structured approach to profile the traffic patterns and requirements of ERP systems on the enterprise network can be advantageous in this stage, such as:

- Structured methodologies to profile traffic patterns and requirements of networked applications typically have a cyclic nature, which, when properly implemented, allows these methodologies to provide an accurate and up-to-date traffic profile of the applications under examination.
- Structure application profiling methodologies potentially can avoid major network problems early in the application implementation process, which can yield substantial financial and operational efficiencies (Clewlett, Franklin & McCown, 1998).
- The cyclical nature of some structured application profiling methodologies allows such methodologies to support multi-year ERP system rollouts and the evolution of ERP systems and networks.
ERP implementations have been known to be extremely complex; hence, the implementation project team usually consists of experts from all relevant disciplines. A formal, structured application profiling methodology potentially can facilitate a better coordination among the application developers, implementers, and network managers.

- Certain application profiling methodologies are implemented within a software suite, such as the operation systems running on Company B’s network monitoring appliance, which allows automatic documentation of the traffic profile over the period of study.

While a structured approach toward profiling ERP traffic patterns and requirements may lead to the advantages discussed previously, a very important objective of this stage of the proposed framework is to obtain the profile with application and subapplication details. To address the issues discussed in this section, content-aware traffic classification, monitoring, and profiling activities are required.

**Evaluating Alternatives**

While the underlying philosophies and technologies differ, bandwidth, separate network paths, and Web-acceleration tools often are considered strong alternatives to network QoS with regard to ensuring the performance of ERP systems on the network. Based on the application and subapplication ERP traffic profile acquired from the previous stage of the proposed framework, as well as other organization factors that influence the necessity of QoS for ERP systems, two related decisions must be made:

- At the higher level, the cost-effectiveness of QoS as a method to ensure the performance of ERP systems must be evaluated against other alternatives. It also is quite conceivable that the most cost-effective solutions are some combinations of the available options (i.e., adding more bandwidth as well as QoS-enabling the underlying network infrastructure supporting the ERP system).
- If the most cost-effective solution involves QoS, another critical decision that relates to selection of appropriate QoS tools must be made.

**Implementation of an End-to-End, QoS-Enabled Network Infrastructure**

The third component of the proposed framework contains a practical architecture for implementing end-to-end QoS:

- First, a practical architecture for implementing end-to-end QoS is presented. This architecture is based on Fineberg (2002) and adapted to provide network QoS to ERP systems that utilize IP networks. Thereafter:

  - A set of guidelines to address the specific issues discussed in this paper.

In Fineberg (2002), a practical architecture for implementing end-to-end QoS in an IP network for VoIP is proposed. Upon close inspection, it appears that this architecture potentially can be adapted to provide network QoS for ERP systems that are supported by IP networks:

- The architecture includes many of the latest QoS technologies and architecture that can be used to provide end-to-end QoS for ERP systems.
- The architecture provides explicit recommendations on the selection of QoS
tools, based on present and speculated future adoption.

- The architecture focuses on delivering end-to-end QoS and, therefore, focuses on enforcing QoS on LAN, WAN, and the internetworking of LAN and WAN. This is critical for ERP systems, due to the fact that ERP systems often are deployed over a geographically dispersed area.

The architecture from Fineberg (2002), therefore, is used and adapted for the purpose of achieving research objective three and is presented in Figure 2.

**The LAN QoS**

The findings from research objective two suggested that CoS (Ethernet), DSCP, ToS, and RSVP all can be used in the LAN to provide LAN QoS. The deployment of IntServ with RSVP signaling has been limited due to its complexity and scalability. However, the deployments of IntServ with RSVP can be realistic in an enterprise LAN for a few reasons, including the following:

- Hosts on the edges of the network now have the ability to utilize RSVP signaling. A host can be an ERP client or server. An ERP client running on the Microsoft platform, for example, may be able to signal its QoS requirements to the network by using the QoS APIs of the operating system.

- The interface (shown as a double line in Figure 2) between the Access Switch (AS) and the Access Router (AR) is the key to provide high-level services. This could be implemented using a distributed broker architecture, such as CORBA, which will equip signaling ERP applications with the capability of stating the functionality desired from the underlying QoS-enabled network infrastructure.

- On the enterprise LAN, it is quite conceivable that the number of network connections is much lower than the number of connections the service provider

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**Figure 2. An architecture for implementing IP QoS for ERP systems**
networks. This potentially can make the flow-based IntServ QoS a practical option on the enterprise LAN.

**The WAN QoS**

DiffServ and MPLS appeared to be the two dominant technologies in the WAN. TCP rate shaping, however, is also another recognized QoS technology in the WAN. Additionally, the internetworking of LAN and WAN QoS involves the following:

- Translation of enterprise LAN QoS settings, as the packets leave the Access Router (AR) for the Edge Router (ER) (i.e., the private DSCP or ToS settings may need to be redefined, as the packet leaves the boundary of the enterprise LAN).
- Mapping of QoS requirements from one architecture to another (i.e., an enterprise may use IntServ on the enterprise LAN, but on the WAN, the service provider uses DiffServ).

**Specific Guidelines for Implementing QoS for ERP Systems**

The network must allow traffic classification by application type, classifying the network traffic at Layer 4. This is a basic requirement for implementing QoS for ERP systems that are running on a converged IP network infrastructure. Application level traffic classification currently can be implemented at many places on the architecture presented in Figure 2. First, the QoS-enabled applications and hosts have the capability of identifying themselves through QoS APIs and RSVP signaling requested at the high-level services interface (i.e., CORBA). Second, the Access Switch (AS) to which the hosts are connected can be used to classify and to mark the traffic, based on TCP/IP port numbers; the AS, however, needs to operate at Layers 2 through 4. The Access Router (AR) also can classify and mark the packets using Layer 4 packet information as packets pass through it.

The network also should allow traffic classification using packet content information. This can be considered a necessity in order for QoS for Web-enabled ERP systems to distinguish HTTP ERP traffic from other HTTP traffic; Layers 2 through 4 classifications are considered insufficient for the provision of QoS and for ERP systems, whose network requirements are highly qualitative. Currently, the traffic classification at Layer 7 can be implemented within AR. Alternatively, the enterprise also can implement Layer 7 classification and packet marking through the use of specialized QoS appliances (QA), such as the ones offered by Company B.

**CONCLUSION AND FUTURE RESEARCH DIRECTIONS**

The findings and proposed framework introduced here are expected to provide value for both theory and practice. The proposed framework for the provision of QoS for ERP systems provides new insights into a number of areas that largely have been ignored by ERP-related research.

It is clear that in order for ERP applications to exploit QoS features, it is necessary to provide functions that facilitate the conversion between high-level management objectives, such as priority process scheduling, and specific application requirements that can be satisfied by the corporate IP LAN/WAN infrastructure. Throwing bandwidth at the problem, as seen in some of the cases discussed in this paper, is a poor substitution for a proper provision of network quality of service. The approach
taken by the framework presented is sounder and allows for a more systematic and controlled use of resources.

The findings from this research also may provide value for practitioners, particularly for organizations with ERP deployments that utilize best-effort IP networks and professional ERP implementers, including consultants from ERP and network technology vendors. It is expected that the value of the research will not diminish significantly in the foreseeable future, as long as the follow assumptions hold:

- The ERP evolution will continue to be influenced by the Internet and the various Web technologies.
- ERP systems will continue to be deployed, possibly by SMEs around the world, and used to support the core business activities of the enterprises.
- The number of converged IP networks will increase gradually.
- The demand for IP bandwidth from the enterprises will continue to grow, and the WAN bandwidth will remain scarce.
- The processing power of network nodes, such as routers and switches, will continue to grow.

Two directions for future research are identified. First, wireless QoS for mobile ERP access. Similar to the wired QoS for ERP systems, which has been the focus of this research, wireless QoS technologies also have been neglected largely by organizations, ERP system vendors, and implementers. There are, however, reported trends of an increasing number of mobile users and a growing usage of wireless devices that provide access to ERP systems (Mello, 2002a, 2002b). Finally, the potential impact of QoS implementations for ERP systems on enterprise and system users has to be taken into account. Prior to network QoS, ERP systems that used IP received no more than two types of network services: the best-effort service provided by the network infrastructure that is dedicated to EPR systems and the best-effort service provided by the converged network infrastructure. With the presence of network QoS, enterprises have the ability to provide differentiated services, based on user and user activity, office location, application, content, time, and any other information that is accessible to the network. It would be conceivable that network QoSs have the potential to influence the existing power structures in enterprises, particularly for users of mission-critical applications, such as ERP.

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