Evolutionary Trends in Intelligent Networks

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ABSTRACT

A number of groups are currently developing technologies aimed at evolving and enhancing the capabilities of intelligent networks. In this article we discuss three of these initiatives: PINT, Parlay, and IN/CORBA Interworking. The IETF PINT work addresses how Internet applications can request and enrich telecommunications services. The Parlay consortium is specifying an object-oriented service control API that facilitates the access, control, and configuration of IN services by enterprise IT systems. The OMG's IN/CORBA interworking specification enables CORBA-based systems to interwork with existing IN infrastructure, thereby promoting the adoption of CORBA for the realization of IN functional entities. We address how all three of these technologies could be deployed together in order to provide a basis for a more flexible and open IN architecture. We also identify a number of common trends and potential pitfalls highlighted by current work on the evolution of IN.

INTRODUCTION

Recent years have seen a huge increase in the penetration of desktop computing in homes and businesses worldwide. This has been fueled, to a large extent, by the success of the Internet, which has clearly demonstrated the immense commercial potential of multimedia communications services. Exposure to the Internet has raised customer expectations of the service features that should be offered by the public telecommunications infrastructure, principally that they support a mix of media types and allow easy customization. Additionally, users expect that these services will be available on demand, regardless of their location or the capabilities of their terminal equipment. While the main technological components required to realize this vision are available, there remains a significant challenge in deploying them in a manner that both is cost effective and can continue to meet the demands of a volatile marketplace.

As the level of interconnection between fixed, mobile, Internet, and enterprise networks increases, a key component in ensuring their ongoing success will be the availability of a common platform for the development and delivery of communications services. Of course, a key requirement for operators who intend to enhance their service delivery capabilities is that existing systems be leveraged as much as possible rather than replaced outright. Many see the intelligent network (IN), which is today the prevalent means of providing services based on manipulation of voice call setup, as a starting point for the service delivery platform of the future. Currently a number of groups are proposing short- to medium-term evolutionary paths for IN aimed at overcoming limitations of existing systems. In this article we discuss some of these initiatives, show that taken together they may provide the basis of a flexible and open architecture, and identify a number of common trends and outstanding issues.

In the next section we outline some of the technical and commercial limitations currently driving the further development of IN. The following three sections discuss Internet/information technology and public switched telephone network (PSTN) integration standardization work carried out by the Internet Engineering Task Force (IETF) PSTN/Internet Interworking (PINT) initiative, the Parlay consortium (Parlay), and the Object Management Group (OMG) — IN/CORBA Interworking (CORBA: Common Object Request Broker Architecture), respectively. The fifth section illustrates, through the description of an example service, that rather than competing, these technologies may each form one element of an integrated service delivery architecture. The final two sections identify important common trends in these developments and some issues for which immediate solutions are not apparent.

DRIVING FORCES FOR IN EVOLUTION

Development of the IN concept has been motivated mainly by a need for a reduction in the time from service conception to deployment in PSTN networks, a desire to free network operators from dependence on particular equipment vendors, and a wish to enable the provision of services by third-party providers. The degree to which existing IN systems meet these goals may be debated; however, IN is clearly a commercial reality, with ever-increasing penetration of IN services and growing demand for ever more sophisticated features that can be customized by the end user. Deregulation of telecommunications markets globally will result in a more open

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environment in which third-party service providers will seek access to the public network infrastructure. These trends point toward a growing necessity to overcome some of the constraints of existing IN platforms.

Inherent Limitations

The majority of IN implementations are still based on the CS-1 standards, which limit IN service logic to control of (voice) call setup in response to triggers activated at network switches. For some time there has been a clear need to extend the capabilities of IN to allow control of calls throughout their duration and to introduce support for multiparty, multiconnection calls, possibly involving the exchange of multimedia data. However, International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) IN CS-2 [1] does go some way toward realizing this goal. In addition, the manner in which IN services are deployed and accessed should be made more open; for example, service logic should be accessible from Internet terminals, and contain components residing in both service control points (SCPs) and Internet nodes. Trigger deployment in switches is also currently a problem since service deployments can require upgrades of switch software.

Service Development and Deployment

As alluded to above, a key motivation for IN was to reduce the time between service conception and full-scale deployment in the public telephony network. While IN has succeeded in cutting this time lag, it is evident that even faster service deployment is required today to satisfy rapidly changing customer demands. However, the necessary improvement may be hard to achieve in the short term because methodologies and tools for service creation and validation have not yet matured to support the degree of automation required for rapid development. To a large degree this is due to the complexity and time-consuming nature of service validation in general and the difficulties associated with detection of unwanted interactions between services in particular. In addition, service components are generally not developed with reusability or customizability in mind; thus, development times for new services may be unnecessarily lengthy. Finally, generic service deployment and management are still not mature technologies.

Vendor/Technology Independence

Stringent reliability and performance targets for telephony services have meant that fault-tolerant equipment and specialized software are necessary for the realization of IN platforms. Variations in versions of communications protocols and service logic mean that in many cases the task of getting equipment from different vendors to interoperate properly is very difficult. These factors contribute greatly to the difficulties for smaller vendors and third-party service providers who wish to enter the IN market. Many see the implementation of IN elements using middleware solutions such as CORBA as offering the potential to overcome these difficulties by making service logic independent of underlying hardware/software architectures and communications protocols.

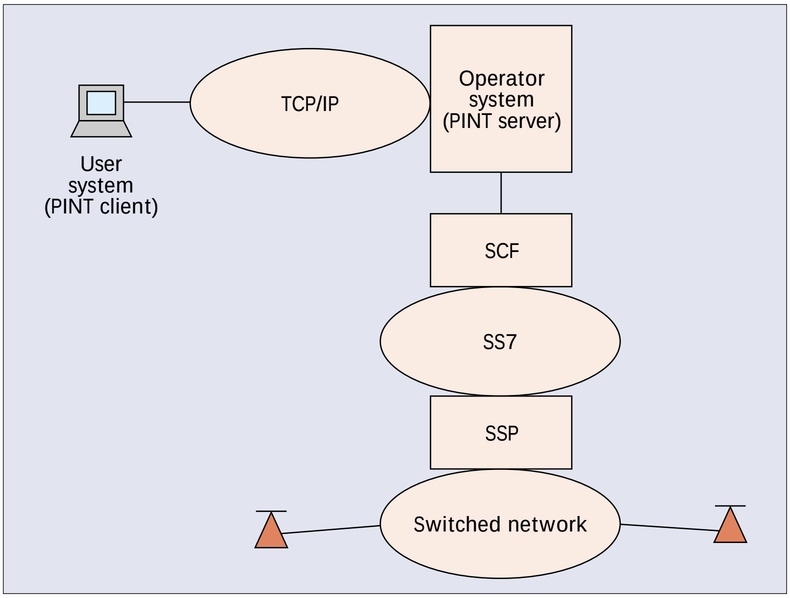

Figure 1. *The IETF PINT architecture.*

Openness

A key barrier to the development of IN into a truly open service environment is the lack of standardized interfaces for service creation, management, and deployment that can be used by nonspecialists to develop IN services using commercial software development methods and tools. These open interfaces may even be tailored for the use of end users wishing to create or customize services to meet their own needs. An additional limitation is a lack of facilities for brokerage of service components that would promote dynamic reuse of IN software. However, this would require significant enhancements to present IN equipment, which, as discussed above, tends to be very proprietary in nature.

Consideration of the limitations discussed above leads to the view that the key requirements for future development of IN are that customers can access a wider variety of services in a wider variety of ways, and that they can customize existing services or even create new ones as simply, quickly, and cost effectively as possible. This requires operators to have more efficient and open service creation, deployment, and management facilities that are integrated into IN service platforms.

PINT

The PINT working group is part of the IETF Transport Area, and was created in 1997 to address how Internet applications can request and enrich telecommunications services. It has published an informational RFC on existing practices in this area and, at the time of writing, is due shortly to issue version 1 of the PINT protocol [2].

The PINT protocol enables the invocation of telephony services from terminals in an IP-based network environment (Fig. 1). More specifically, a host in the IP network forwards a service request to a PINT server, which relays the request to the relevant PSTN network resource, such as a node implementing a service control function (SCF),

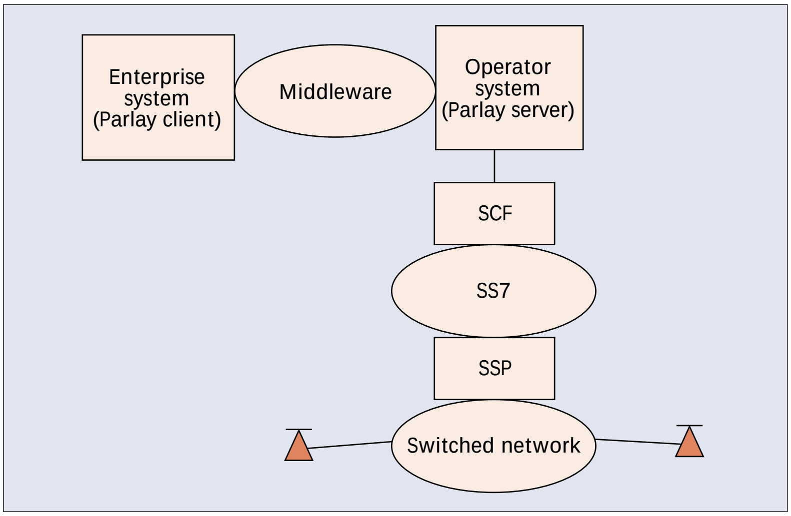

Figure 2. *The Parlay architecture.*

which then executes the requested service, possibly reporting service session status back to the originating IP terminal. Version 1 of the PINT protocol focuses on a small number of "milestone" services, namely Request to Call, Request to Fax, and Request to Hear Content. The protocol is specified as a profile for use of the IETF standard Session Initiation Protocol (SIP), and specific extensions to SIP and the associated standard Session Description Protocol (SDP).

While the overall aim of the PINT initiative is to enable integration of Internet resources and telephony services in broad terms, it will effectively standardize access from the Internet to the IN SCF. It will also enable development of novel services that execute partially in the Internet domain and partially in the traditional telephony domain. Another consequence is that due to the reuse of standard IETF protocols and methodologies, the solution provided will be very lightweight in nature. Importantly, the PINT protocol fits into the existing SIP architecture for Internet-based media session control, which will be significant in the future if SIP forms the basis for IP telephony. From a broader business perspective, important factors pointing toward the likely success of PINT are the fact that the IETF standards process is proven in producing timely, flexible, scalable, and extensible protocols, and that nearly every major telecommunications equipment vendor and operator participates in the process. In addition, PINT is being actively considered by ITU-T SG11 for inclusion in the IN CS-4 functional architecture.

A potentially significant drawback of the PINT work is that no standard application programming interface (API) will be defined as part of the IETF process. This will either lead to an emergence of a de facto standard API or a multitude of vendor-specific implementations with resultant porting difficulty for code to run on different products. Indeed, as seen with past IETF standards, the lack of specification rigor may mean that it will take several years of vendor implementation experience before a high level of interoperability is achieved. In terms of interoperability we also note that interworking between the PINT gateway and the SCF is currently unspecified, although it is potentially a useful interoperability interface (it may be considered by ITU-T SG11).

From a more holistic viewpoint, it can be argued that PINT is quite limited in scope — it prevents IP hosts from participating directly in call control. Because such a capability would greatly enhance the possibilities for hybrid Internet/IN services, the IETF has started the Service in the PSTN/IN Requesting an Internet Service (SPIRITS) working group [3], which is addressing the use of Internet resources by SCFs during service execution. Another factor to consider is that PINT competes, albeit indirectly, with other initiatives such as SIGTRAN (addressing transport of SS.7 protocols over IP) within the IETF and external initiatives like ETSI TIPHON, which is also addressing integration of IP telephony and IN.

PARLAY

The Parlay Industry working group was formed in April 1998 to specify an open API for telecommunications service control. Version 1 [4] of the specification was issued in late 1998. The consortium is now working on version 2 of the Parlay specifications and has grown in membership to include BT, Ulticom, Microsoft, Nortel Networks, Siemens, AT&T, Cegetel, Cisco, Ericsson, IBM, and Lucent.

The Parlay group aims to specify an object-oriented service control API that is independent of underlying communications technologies (PSTN, wireless and IP networks). The API is specified in Universal Markup Language (UML) and is designed to support all major middleware technologies (DCOM, CORBA, Java Platform). The technical goals of the group include encouraging computer-telephony integration (CTI), allowing enterprises' IT systems to access, control, and configure traditional telephony IN services, providing a unified abstract service control interface for heterogeneous media network types (PSTN, wireless, and voice over IP, VoIP) and specification of value-added framework services such as online brokerage and billing mechanisms. Business goals include creating a market for third party service providers, enabling services that are more customized to individual enterprise needs, enabling smaller IT companies to develop telecommunications services and allowing network operators to sell access to their IN infrastructure.

The Parlay API enables a new generation of customer- or third-party-controlled services which are integrated into IT systems such as e-mail, customer information databases, and so on. These services will directly use the telecommunications operators' IN capabilities without the need for wasteful call routing through private branch exchanges (PBXs) for redirection into the operator network (Fig. 2). It is envisaged to promote rapid development of tailored services which allows use of general-purpose IT systems, thus reducing costs and increasing the availability of tailored services to small and medium-sized enterprises. The support of a large number of telecommunications equipment vendors, major network operators, and, vitally, the dominant enterprise IT solutions provider indicates potential rapid prolif-

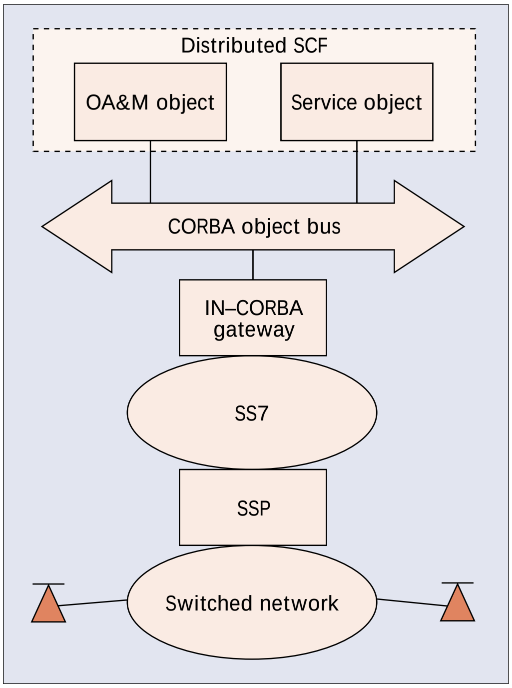

Figure 3. *IN/CORBA interworking.*

eration of this technology. Careful consideration of existing IN capabilities ensures that the API provides an easy evolution path from the traditional IN. Novel features of the API, such as online service brokering and framework interfaces for essential supporting functionality such as billing, combine to make a very complete solution. The API supports the current business and regulatory drivers toward third-party service providers and the reselling of operator IN functionality.

There are, of course, limitations to the work the Parlay group has done so far. It is important to note that the current version (1.2) of the API includes large areas for further study. This includes many of the operation, administration, and management (OA&M) features that make the solution so attractive. It is unlikely that there will be any clear winner of the current competition for dominance of the middleware marketplace, especially in the problematic domain of real-time service control. The technology-independent approach of the consortium guards against this, but will provide interoperability problems as multiple vendors claim Parlay compliance but only support one (or a subset) of the possible middleware implementation mechanisms.

Of course, the nonspecific middleware approach also guarantees that while Parlay may be implemented with any technology, it is unlikely to be optimal since compromises must be made to ensure cross-technology support. Being middleware-based and the size of the planned API ensure that Parlay may be, fairly or unfairly, viewed by the marketplace as a heavyweight solution. It is also apparent that the promise of an abstract service control interface for heterogeneous connections is not fully realized in the current specifications. There will be problems for future development in this area since very dissimilar call control mechanisms, such as SIP and Intelligent Network Application Protocol (INAP), are integrated under one API. The result may well be that only very basic call control may be exerted over such connections.

IN/CORBA Interworking

CORBA is a software architecture, defined by the OMG, which enables software objects to interact with each other despite their location, type of host computer, or programming language. Improved system scalability, increased software reuse, ease of distribution, implementation language independence, and object orientation are seen as the main benefits of adopting CORBA for large-scale application development. In September 1998 the Telecoms Domain Task Force of the OMG produced a specification [5, 6] focusing on the interworking of CORBA-based systems with telecommunications signaling systems, such as IN and mobile systems (Fig. 3). This standard resulted from a joint submission by AT&T, GMD FOKUS, Nortel, IONA Technologies, and Teltec Ireland, in collaboration with Alcatel, Deutsche Telekom, Ericsson Telecommunications, Humboldt University, Object Oriented Conceptes Inc., and Telenor, and is currently at the implementation and review stage.

The primary technical motivation for the IN/CORBA interworking specification is to provide mechanisms for interworking of the existing service infrastructure, which uses transaction capabilities (TCs) for communication, with CORBA-based service objects, which use an Inter-Object Request Broker Protocol (IOP) for communication. The specification defines a framework for design of CORBA-based TC-user applications, such as INAP, which may communicate via a gateway with legacy TC-users such as service switching points (SSPs). An additional part of the specification allows interworking between islands of CORBA-based systems using the existing Signaling System 7 (SS7) infrastructure as a transport network for CORBA messages between, for example, switches that expose CORBA interfaces and CORBA objects providing service logic.

Middleware technologies like CORBA are increasingly seen as the appropriate infrastructure for future service networks due to the inherent technological advantages brought to bear by distributed object-oriented processing environments. Indeed, CORBA has already been recognized by the American National Standards Institute (ANSI) T1 Committee as the basis for defining a framework and generic network information submitted to the ITU-T in an attempt to develop international standards for CORBA-based network management interfaces [6]. In the same vain, the CORBA interfaces provided by the IN/CORBA specification provide standardized interfaces which allow more open and distributed implementations of IN services. Also, the common CORBA approach to management and service provisioning produces a more integrated network and less cumbersome service management. IN/CORBA also facilitates increased interconnection capabilities with external resources such as the Internet and private databases. The approach has the added advantage of providing a homogeneous interface for any SS7 protocol stack implementation. This independence reduces tech-

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CORBA still has shortcomings when expected to operate in a highly fault-tolerant real-time environment, as is expected of telecommunications systems. Indeed, these issues are not addressed directly by the IN/CORBA Interworking specification.

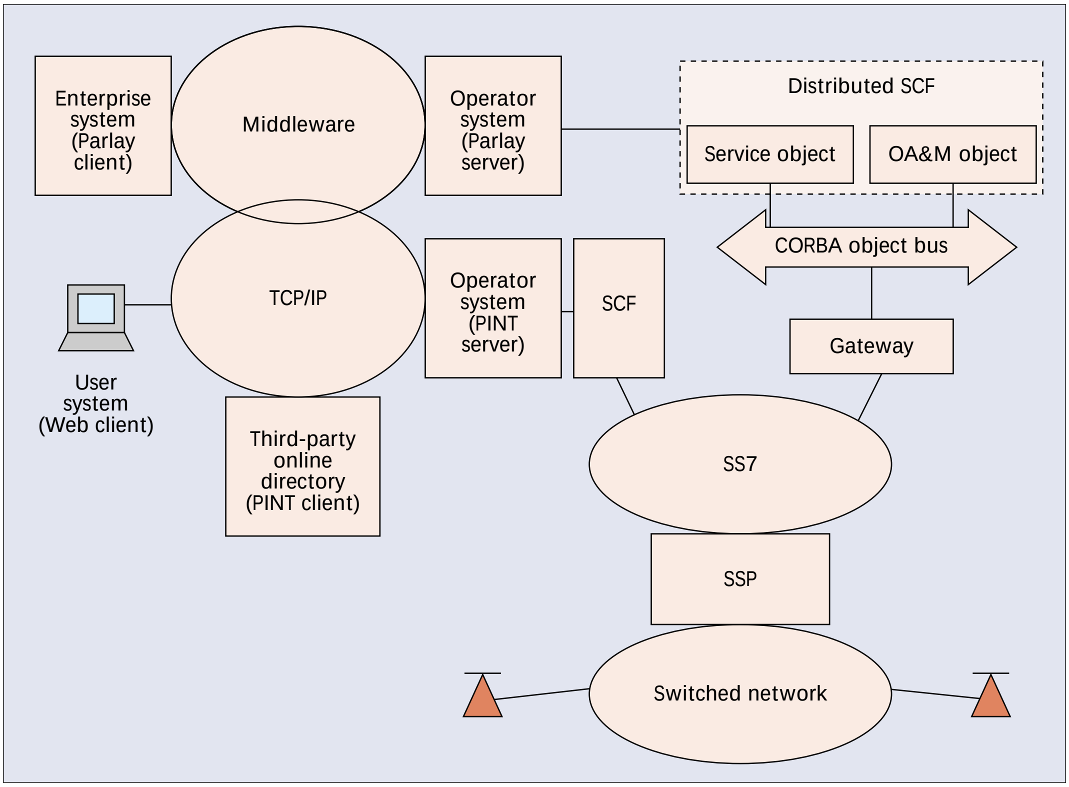

Figure 4. *A short-term scenario.*

nology lock-ins, allowing service creation that is independent of proprietary SS7 protocol stack implementations. OMG standards also have the desirable feature of fast standardization and short time to market. Becausethe specification enables implementation of both CORBA-based IN and MAP systems, it may also provide a common ground for fixed-mobile convergence. Leverage of existing off-the-shelf CORBA services, such as security, naming, messaging, and notification, can also help accelerate application development.

Although the IN/CORBA approach presents many possibilities for the future of IN, there are some associated drawbacks. In order to maintain generality, the solution is quite low-level and does not provide support specifically for IN service development. CORBA still has shortcomings when expected to operate in a highly fault-tolerant real-time environment, as is expected of telecommunications systems. Indeed, these issues are not addressed directly by the IN/CORBA Interworking specification. From a more general viewpoint, since CORBA standardization is controlled by an IT industry body rather than a telecommunications body, it may be difficult to impose telecommunications systems requirements on standards based on an architecture for implementation of more general-purpose distributed systems.

A Short-Term View

Given the range of possible technologies, many routes to network enhancement are available. In this section a scenario, illustrated by Fig. 4, is discussed to show how the various technologies described above may be deployed to enable new service offerings and business opportunities. Although this is just one of many possible heterogeneous network scenarios, particularly likely linkages have been exploited where possible. Thus, the customer-oriented middleware approach of Parlay has been coupled with the operator- friendly deployment of a distributed service management and SCF based on CORBA. Through the traditional INAP interworking capabilities of the IN/CORBA solution these functional entities may cooperate with more traditional IN nodes in the network to deliver sophisticated services. Since Internet connectivity drives many services, a PINT server/gateway has been added to an otherwise traditional service control function. Due to the deployment of INAP CS-2 as the basic service control protocol, this PINT-aware SCF may cooperate with other SCFs when delivering services.

In this case, a mix of additional related but complimentary facilities have been added to the IN. In this dynamic environment no one technology has been dominant, and existing investment in advanced service delivery mechanisms has been protected. To show how these facilities can be used in a coordinated manner we will describe an example service that allows users, through the use of a Web-based interface, to have a human support agent telephone them.

An Example Service: Online Yellow Pages for a Distributed Call Center

Our example network operator provides Web-based yellow pages for its enterprise customers' free-phone (toll-free) numbers and has chosen to subcontract a third-party online directory provider for this work. This is supported by a PINT-based solution to add a click-to-dial capability to the online phone book. One customer has used Parlay to build a free-phone premium support number that routes calls to support personnel based on an internal duty roster database and an internal database of the mobile phone numbers of support personnel.

Service deployment and configuration are performed via the Parlay framework interfaces, which in turn trigger a CORBA-based service management system to configure the operator network. Service execution takes the following steps:

- A PINT elemental service (click to dial) is initiated by the end user at the online directory provider's site.
- The PINT server at the network operator's site handles the PINT request and supplies the call initiation information to a collocated INAP CS-2 SCF.
- From the requested number the SCF determines that additional handling information is required from the CORBA-based SCF and starts an INAP CS-2 SCF–SCF relationship with the controlling SCF. The IN/CORBA gateway maps between the INAP session (and destination Global Title) and the CORBA TcUser association with the correct service object(s) within the CORBA-based SCF.
- The CORBA-based SCF initiates a Parlay session to the enterprise system, which returns a suitable routing address based on current time and the local duty roster and mobile number databases. Additionally, the enterprise accounting system is updated with details of the call.
- The controlling SCF then initiates a call between the appropriate support person and the PINT client's phone.

Our definition of the term *service* is necessarily loose in this example since multiple traditional and next-generation telecommunications services are combined into one perceived service for the end user. Of course, similar scenarios may be achieved with currently available vendor-specific solutions. These systems are typically inflexible, less integrated, and incapable of deployment in multivendor environments.

Common Attributes of IN Evolution Paths

Although it is impossible to exactly predict how the current standardization efforts will impact the intelligent network of the future, the scenarios presented here do point toward some overall technological and business trends. This section attempts to identify these key trends that will have a far-reaching impact on service providers, network operators, and service subscribers.

From the viewpoint of the emerging standards, one of the key features in current thinking is the use of generic middleware technologies such as CORBA. Middleware will be used for the provisioning of distributed service logic in an open market environment and also to provide a platform for leveraging of resources, such as the Internet, which are largely isolated from the current IN. Conversely, the use of middleware and generic protocols also opens the network for access to and from other domains. The trend of standardizing fine-grained middleware interfaces allows the possibility of smaller, more manageable standard software components making up an overall service architecture. This in turn allows a more open marketplace with opportunities for many independent service vendors and third-party service providers, the presence of whom makes it easier for operators to minimize technology lock-ins.

Standardization of bridging interfaces is also a common trend, allowing the merging of currently isolated enterprise, public, and private service networks such as PBXs, intranets, the Internet, and existing INs. This will enable more complex and flexible services to be offered. Access by differing terminal equipment will be coordinated more easily and interact to provide the subscriber with more powerful interfaces for service subscription, access, and configuration.

A general trend found in current standards work includes the use of generic IT software solutions for acceleration of the development cycle, sophisticated service provisioning, increasing the size of the recruitment pool of knowledgeable staff, and lowering costs by avoiding specialist solutions. This has the effect of allowing service execution to be distributed across many domains, allowing reuse of existing service networks in new ways, and allowing access to services by different users with different terminals than originally intended.

Figure 5 describes pictorially how, based on the technologies discussed here, different elements of existing and future technologies may combine to form the future network as seen from the service provider, network operator, and subscriber viewpoints.

IN Evolution Challenges

The future direction of IN development is uncertain, as even the subset of possible approaches discussed in this article suggests. Since there are common themes that run through the various technologies, there are common pitfalls and deficiencies to be contemplated. In this section some of the more pressing issues are discussed.

Difficulty of Specification

A common pitfall for evolution technologies is the specification of an enhanced service architecture which is dependent on other technologies which are not yet mature enough to be deployed (and hence may never be deployed due to other market forces). All of our chosen technologies are specified by IT or communications technology fora which depend on rapid implementation and wide-ranging industrial participation for specification adoption. However, only IETF PINT is unhindered by dependencies on middleware technologies which may delay deployment of either Parlay or OMG IN/CORBA Interworking solutions. Of course, IETF PINT has a much more limited scope. which will also be key to its rapid implementation and deployment. Technical difficulties with any proposed change in the existing IN architecture will not always be immediately apparent from specifications — actual implementation experience is always required.

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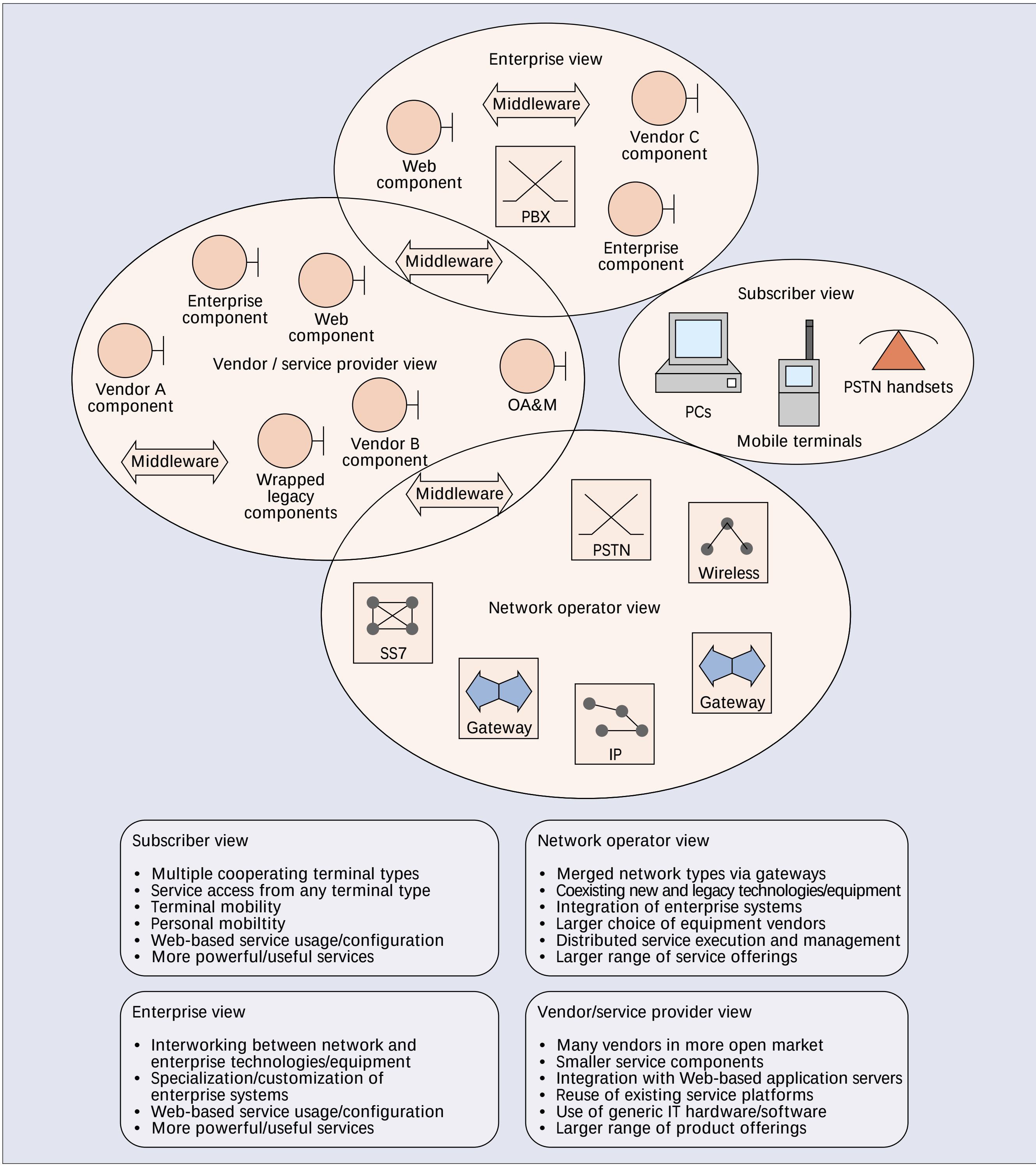

Figure 5. *Common attributes of IN evolution paths.*

NONFUNCTIONAL REQUIREMENTS OF TELECOMMUNICATIONS SYSTEMS

Performance and reliability will always be key attributes of telecommunications systems that are not traditionally present in enterprise IT systems. There are several facets of the technologies presented in this article on which this has an impact. Service logic distribution, a common attribute of all these systems, involves a communications and processing cost which will have to be justified in terms of the added capabilities or other savings. TCP/IP networks are generally envisaged as the transport for the protocols supporting the new technologies, and it is well known that they are currently less well suited to telecommunications demands in terms of predictability, congestion avoidance, and reliable fault recovery [7] than the well established SS7 family of protocols used for traditional signaling applications. Finally, middleware solutions have not yet proven themselves capable of the high availability requirements (minutes downtime per year) of the telecommunications service network.

FRAGMENTATION OF STANDARDIZATION ACTIVITY

Maintaining and expanding network elements based on one or more families of network protocols has always been a major effort for operators and vendors. However, we now have a situation where the number of design ideologies is expanding from the traditional telecommunications (e.g., ITU-T) view to include data communications (IETF) and distributed object technology (CORBA/Java/DCOM). This brings with it differing approaches to protocol design that may have to be accommodated within one product. This will increase training costs for staff and reduce the number of common software elements in a network element. Of course, the overall vision for evolution will also be split among differing bodies with the likely result of a gradual decline in the size of evolutionary steps. Hopefully, this will lead to a more dynamic environment where gradual change is more normal and advances may be introduced into the network more easily. Alternatively, more and more processing power and development effort may be devoted to maintaining backward compatibility and interworking between almost compatible solutions.

A BRAVE NEW WORLD

Finally, the very act of opening up operator networks will have a profound effect on issues such as security, dimensioning, network planning, fault management, and network integrity. Traditionally closed worlds, operator networks will be forced to evolve to include complex gateway functions which both protect the network and monitor external usage for legal and accounting purposes. Although similar situations can occur today in the case of interprovider agreements, the scale of the problem will be enormously magnified if and when any small to medium enterprise or individual can have such an arrangement with a provider. Large-scale issues of network strategy are also looming. Many operators are currently both transport and service providers. Is this the best way to sustain growth? Ease of IT integration and the proliferation of data network access for individuals will force operators to provide a more dynamic environment. This interconnected world will provide challenges for today's hierarchical management systems, and thus requires new solutions to be in place.

CONCLUDING REMARKS

The world of IN standardization and evolution is changing. There are many disparate bodies involved in the work; a mix of both traditional telecommunications and information technology solutions will soon be widely deployed. There will be both successful and unsuccessful specifications, but there are several underlying trends in the IN evolution path that will be present in future systems. Due to the energy being put into new technologies and their ability to open new markets, it is likely that the pace of change will continue to accelerate.

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BIOGRAPHIES

ROB BRENNAN (brennanr@teltec.dcu.ie) received a B. Sc. in applied physics from Dublin City University, Ireland, in 1992, and an M. Sc. in computational science from Queens University Belfast in 1994. He then worked from 1994 to 1997 on standards-based messaging and directory systems development for ISOCOR B.V. Since 1997 he has been a research officer at Teltec Ireland, a telecommunications research institute funded by the Irish government, working within the Intelligent Networks group. He is chair of the OMG IN/CORBA finalization task force and an editor of the original specification proposal. In 1998 he began a Ph.D. degree in next-generation telecommunications services with Dublin City University. His research interests are in the areas of distributed systems, performance, hybrid internet/telephony services, and agent technology.

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THOMAS CURRAN (currant@eeng.dcu.ie) received a Ph.D. in electronic engineering from University College Dublin in 1982. He then joined Dublin City University, where he is currently a senior lecturer in the School of Electronic Engineering. During the course of his career he has undertaken extensive consultancy activities of a planning, design, and marketing nature, in diverse areas such as PBX, X.25, and data networks, networking multiplexers, public network management, and switching systems. He has participated in ECMA and ETSI standards bodies covering frame relay, private telecommunication network, broadband, and IN. His current research interests relate to IN, IP telephony, performance management, and network design. Since its inception in 1991 he has been director of the Teltec Ireland center at Dublin City University.

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