Real-time routers for wireless networks

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Through the introduction of a novel breed of routers that have been optimized for use in wireless networks, Ericsson has opened a new era of wireless IP. Being based on existing and emerging industry standards, the real-time routers will enable operators to reap the full benefits of all-IP networks—for example, the routers feature a dual IPv4/IPv6 stack for optimum scalability and security, an advanced quality-of-service mechanism for delay-sensitive traffic, hardware accelerators that yield outstanding performance, automatic configuration for reduced operational expenditure, and operation on a true telecommunications-grade platform with no single point of failure.

The Internet protocol is making its way into wireless networks. Having been enhanced in terms of efficiency and quality-of-service support, the Internet protocol has matured and can now be used to transport services in wireline as well as wireless systems. Nonetheless, the use of IP on the fixed network side of wireless systems puts special requirements on networking equipment, such as IP routers, base stations, radio network controllers and gateways.

The authors describe Ericsson's real-time routers, which have been specifically designed to cope with the special conditions of wireless networks, including network synchronization, narrowband links, and applications that are sensitive to delay.

What is a real-time router?

A router is a packet-switching device used to interconnect several different networks to form a common network that is based on IP networking technology. Based on its understanding of the networks to which it is connected, the router decides how each packet is to be forwarded. In addition, real-time routers must

- be able to differentiate between high-priority and low-priority packets;
- forward high-priority packets with low latency as well as low delay variation;
- always be free of internal congestion; and
- contain mechanisms that prevent large packets with low priority from blocking small packets with high priority on slow links.

Real-time routers enable operators to build IP networks for demanding, real-time services, while exploiting the capacity of the entire network and providing traditional, best-effort IP services using spare capacity.

Real-time routers for wireless networks

To the operator, all-IP networking has several advantages:

- simplicity and reduced costs—a unified network is easier to manage, requires less capital, and results in lower operating expenditures;
- transmission gains—packet-based technology makes more efficient use of links;
- profit from the development of sublayer technologies—new and better transmission and link solutions can easily be introduced into the network;
- new sources of revenue—a unified network layer spurs the development of applications and facilitates accessibility; and
- IP for remote access—secure virtual private networks (VPN) can generate substantial savings for corporations and residential users.

To realize the vision of a system of all-IP networks, advanced, real-time routers must be introduced throughout the wireless access network, to provide the necessary transport of real-time services. Embedded routers in base stations or stand-alone aggregation routers serve as concentrators that optimize the use of transmission links by means of statistical multiplexing.

If, however, the access network is not based on the Internet protocol, but the system to which it belongs employs an IP-based connectivity backbone, then real-time router functionality must be introduced at the gateway nodes that interface the IP connectivity backbone. Inside the IP connectivity backbone, real-time routers handle the flow of aggregate traffic from the wireless access networks. Due to the higher capacity of the links, the requirements for efficient handling are lower in this network;

BOX A, ABBREVIATIONS

ATM	Asynchronous transfer mode
BSC	Base station controller
CLI	Command line interface
DEN	Directory enabled networking
DHCP	Dynamic host configuration protocol
DiffServ	Differentiated Services standard
ET-FE	Exchange terminal with forwarding engine
FEHW	Forwarding engine hardware
FPGA	Field programmable gate array
FTP	File transfer protocol
GSM	Global system for mobile communication
GSN	GPRS service node
GUI	Graphical user interface
HLR	Home location register
HTML	Hypertext markup language
ICMP	Internet control message protocol
IP	Internet protocol
IPsec	Internet protocol security protocol
LDAP	Lightweight directory access protocol
MIB	Management information base
MPB	Main processor board
MSC	Mobile services switching center
NCMS	Network configuration management system
NPMS	Network performance management system
O&M	Operation and maintenance
OSPF	Open shortest path first
PPP	Point-to-point protocol
QoS	Quality of service
RMON	Remote network monitoring
RNC	Radio network controller
RNS	Radio network server
SCB	Switch core board
SNMP	Simple network management protocol
SXB	Switch extension board
TCP	Transmission control protocol
UDP	User datagram protocol
UMTS	Universal mobile communication system
VPN	Virtual private network

that is, the granularity of quality of service (QoS) separation is less critical, due to lower transmission delays for packets on high-speed links (Figure 1). Real-time routers for wireless networks must efficiently be able to handle small packets, low-speed links, delay-sensitive traffic, synchronization, a large number of nodes, and continuous, always-online connections.

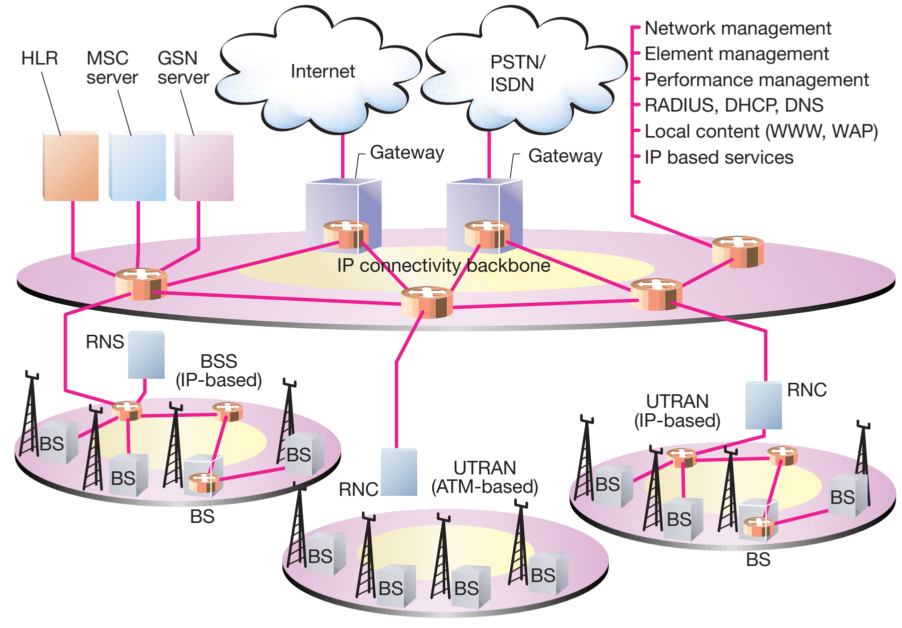

Figure 1
Future wireless IP networks will play a key role in transporting services. In this example, the Internet protocol carries voice and data in the operator network. Media gateways are used to interface external networks. The real-time router—pictured as a stand-alone router in the radio network and as an integrated router in base stations and gateways—ensures real-time characteristics throughout the network.

Small packets

Present-day cellular networks transport voice in short speech frames that typically carry 20 ms of compressed voice. Each speech frame contains between 10 and 40 bytes of data. Given such small packets, the overhead of IP and transport layers becomes an issue. Thus, an effective header compression scheme must be implemented in the router. In particular, this applies to access networks. Nonetheless, header compression might also be employed to save bandwidth as the small packets enter the core network. A more important consideration, however—to minimize router load—is to ensure that the routers of the core network are not required to route each individual voice packet. In short, IP-level voice trunking must be implemented to benefit from the high speeds of the links in the core network.

Low-speed links

Access links in present-day radio networks are typically low-speed—often 2 Mbit/s or less. On these links, small, delay-sensitive packets compete for bandwidth with large, low-priority data packets. For example, if a high-priority voice packet arrives at the router on a 384 kbit/s link just as the router begins transmitting a large packet, then the voice packet runs the risk of being delayed by up to 30 ms. Obviously, this is unacceptable, since the delay budget in wireless networks is very tight for voice transmission—in particular, because other equipment, such as transceivers and transcoders, has already consumed most of the delay budget. Thus, an effective mechanism must be implemented in the router to ensure that the transmission of low-priority packets does not unduly block or delay voice packets.

Delay-sensitive traffic

A large portion of the traffic carried over wireless IP networks consists of voice and other delay-sensitive services. Accordingly, this traffic and its related control data must be given priority over other traffic. Given the low-speed links of wireless access networks, more effective QoS separation must be introduced with more classes than those required in the backbone network. That is, compared to those of ordinary data communication networks, routers for wireless networks must include more extensive and intelligent quality-of-service implementations.

Synchronization

As elsewhere, radio base stations in wireless IP networks must be synchronized. The routers for wireless networks must be able to provide radio base stations with a high-quality synchronization signal that is distributed via transmission links between routers and base stations. This requirement has not been considered or cannot be met by most present-day datacom router products.

Large number of nodes

Implementations of wireless IP networks will consist of thousands of routers, many of which will be embedded in radio base stations. Consequently, new approaches must be applied to the automatic address and node configuration, which integrates advanced traffic engineering and network planning tools. Work in this area stands to benefit

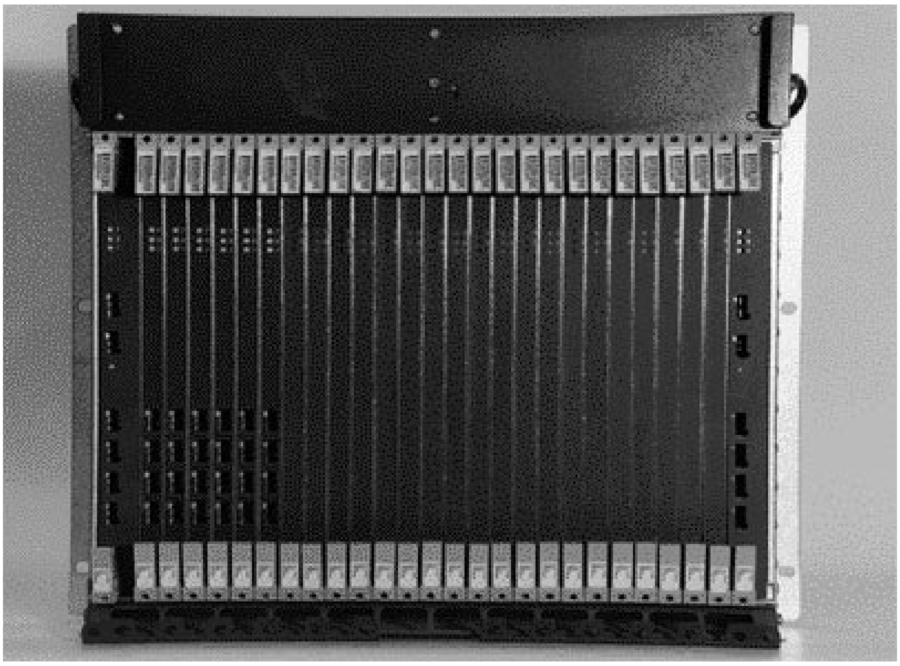

Figure 2
With dual-switch cores (in right-most and left-most positions) and 26 generic slots for processors and interfaces, Ericsson's real-time router embodies high density and redundancy.

from the use of directory-enabled networking (DEN) by means of lightweight directory-access-protocol (LDAP) configuration servers. Likewise, advanced features for automatic configuration will be made available if IPv6 is chosen as the IP networking layer (Box B).

Always connected, always online

Looking ahead, we foresee that the number of Internet-enabled mobile terminals (mobile phones, smart phones, communicators, PDAs, and so on) will greatly multiply. Moreover, we will see many embedded devices and the widespread use of the Internet protocol in wireless consumer devices. Ideally, every device worldwide should have the opportunity to be connected and online at all times. Simple, convenient and immediate wireless connectivity is a key enabler for rapid growth in the market. Nonetheless, the connected society will require a huge number of IP addresses. Here again, the capabilities of IPv6 are expected to play an important role.

Ericsson's real-time routers

The Ericsson real-time router, which is based on the Cello platform[1], can be deployed as an embedded router or as a stand-alone real-time router. As an embedded router, it can serve as an integral part of other products based on Cello, such as

- radio network controllers (RNC) for UMTS;
- radio base station controllers (BSC) for cdma2000; and
- media gateways for packet data services and voice services.

When used as a stand-alone device, Ericsson's real-time router targets the aggregation of traffic in the wireless access network close to base stations. It contains all necessary functions for interfacing base stations in various IP-based systems; for example, optimizations of low-speed links, advanced QoS handling, and the distribution of network synchronization. It can also serve as an IP connectivity network router, providing up to a few Gbit/s total capacity.

Regardless of whether the router is deployed in an embedded or stand-alone configuration, it features the same routing software, interfaces, and operation and maintenance (O&M) support. To the network layer, it is merely another router, regardless of other functionality in the node.

BOX B, IPV6—NEXT-GENERATION INTERNET

The Internet protocol version 4 (IPv4) was developed in the early 1980s. With the ever-increasing success of the Internet, it became apparent to the Internet Engineering Task Force (IETF) that a new version of the protocol would be needed to handle growth and new requirements stemming from new applications. To this end, the IETF drafted a family of specifications—request for comments (RFC)—that make up the IPv6.

The main differences between IPv4 and IPv6 relate to scalability, simplicity and security. One of the shortcomings of the IPv4 is the limited number of addresses. In theory, the total number of addresses is four billion (32-bit address field), but the way in which addresses are allocated greatly reduces the actual usable amount. With the promise of communication between PDAs, embedded devices, and always-connected, always-online wireless devices, the global demand for addresses is expected to increase dramatically. Consequently, IPv6 with its 128-bit address field is a most welcome enabler.

For the sake of simplicity, IPv6 provides new automatic configuration mechanisms that make the building and reconfiguring of networks much less cumbersome. This is especially significant to

- wireless networks—where the potential number of IP nodes is large;
- companies who might want to change Internet service providers; and
- companies who might want to merge their operations.

IPv6 provides built-in support for IPsec. Thus, together with a unique and publicly routable address for each individual user, IPv6 can provide a higher level of end-to-end security than IPv4 implementations, which often have to rely on private, non-publicly routable addresses.

While IPv6 was under development, several amendments were made to IPv4. While these workarounds will extend its life, they do not resolve the fundamental issues of scalability and end-to-end security for every user.

Ericsson's recent acquisition of Telebit S/A, gives the company a commanding lead relative to routers that are capable of handling IPv4 and IPv6 simultaneously.

For more information on IPv6, see http://www.ipv6.org.

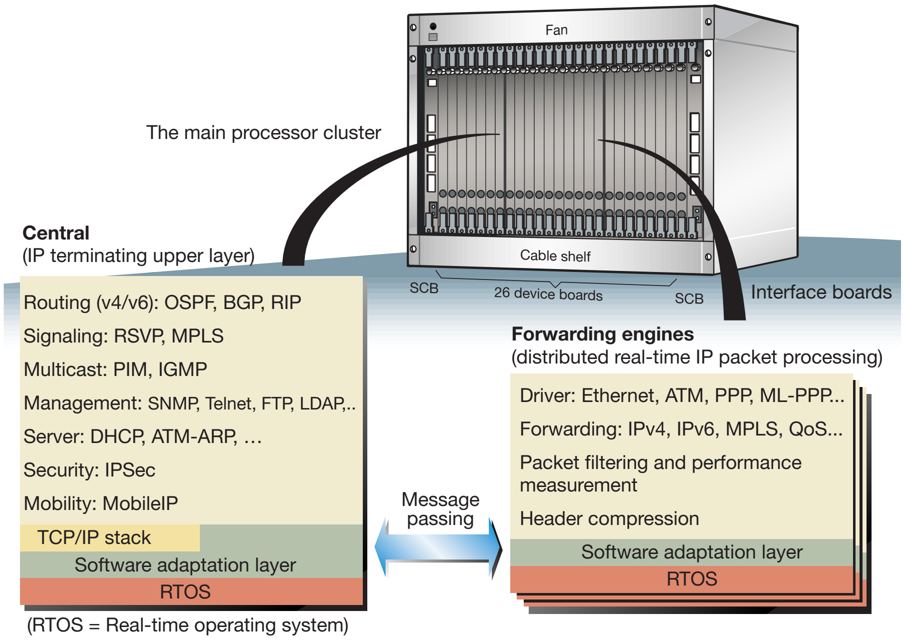

Figure 3
The real-time router comes with a distributed architecture with a feature-rich suite of software protocols that has been optimized for wireless conditions. The use of distributed forwarding engines (implemented in hardware) enables the router to be scaled linearly. This guarantees real-time characterstics at all interfaces simultaneously.

The real-time router, which is designed for dual IPv4/IPv6 operation, features a truly distributed architecture with a scalable main processor cluster and interfaces with hardware support for IP by means of forwarding engines (Figure 2) that have been implemented in hardware (FEHW).

A benefit of the distributed router architecture is that the system scales well, since packet-processing power is augmented with each added interface (Figure 3). The central processor cluster can thus use one or more main processor boards (MPB). Each MPB makes up a modern software-execution environment used primarily for central tasks in the router, including

- unicast routing protocols for IPv4 and IPv6;
- multicast routing protocols for IPv4 and IPv6;
- network management support (simple network management protocol, SNMPv3, and command line interface, CLI, through Telnet or console);
- performance management support (remote network monitoring, RMON);
- IP security (IPsec) and key distribution; and
- the handling of Internet control messages (Internet control message protocol, ICMP).

The forwarding engines (FEHW), which are used on the interface boards for IP (ET-FE) to accelerate routing and link handling (Figure 4), use configurable hardware technology (FPGA) to implement their functions. This guarantees flexibility now and in the future, since installed boards can be updated remotely. The forwarding engines feature advanced functions for individual IP packet handling:

- IP forwarding with longest prefix match;
- support for fine granular QoS separation in accordance with the Differentiated Services, or DiffServ, standard;

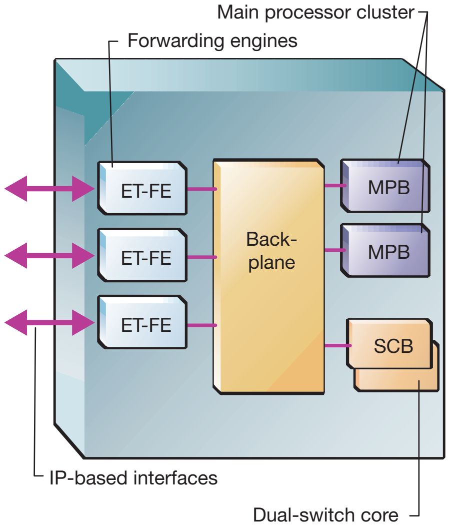

Figure 4
Single subrack configuration.

- prioritized packet scheduling with support for expediated forwarding and multiple assured forwarding classes and levels;
- header compression for E1, T1 and J1 interfaces; and
- the collection of statistics for performance monitoring.

These functions are implemented in hardware in order to support a high rate of packets per second in the router. As mentioned above, the traffic in wireless networks is often dominated by small voice packets—which, compared to the traffic of traditional data communications, yield a high packet rate. Nonetheless, hardware-supported IP forwarding significantly lowers packet delay through the router, making it easier to predict the duration of delays, which is a prerequisite for delay-sensitive applications, such as telephony.

The real-time router is unusually configuration-friendly; that is, it accommodates numerous configurations in a flexible manner. The physical structure consists of

- a 19-inch rack with 26 generic slots for processor boards or interfaces;
- single or duplicate switch cores with up to 16 Gbit/s throughput capacity;
- FEHW-supported interface boards, currently for the point-to-point protocol (PPP) over a range of interfaces from 1.5 to 155 Mbit/s;
- support for 1.5 to 155 Mbit/s ATM interfaces used together with IP routing in pooled devices; and
- FEHW-supported Fast-Ethernet interfaces.

Additional interface types will be added to the real-time router as required. Interfaces with speeds above 155 Mbit/s will be added when the networks targeted by the real-time router require them.

Multiple subrack configurations (whose extra slots allow interfaces or processors to be connected) can be constructed by linking the switch core boards (SCB) of several racks or by adding switch extension boards (SXB). The system has high board density (small footprint) and no single point of failure (telecommunications-grade reliability).

The real-time router protocol suite

Ericsson's real-time routers are founded on a common software base for internetworking protocols. All protocols are available in modular distributed software. Certain time-critical functions that relate to per-packet handling, are also available as a protocol subset implemented in hardware for use directly in the interfaces with the FEHW. The software architecture features an "any-process-at-any-processor" design, which permits distributed processing of protocols in the Cello processor cluster and yields a very scalable solution to which new processors can be added to handle specific protocols. What is more, because the protocol suite was designed to be ported to different platforms, it can also be used on other, non-Cello platforms, such as GSM or TDMA base stations.

The benefits of running the same software on all routers in the network are that

- true real-time characteristics can be obtained, thanks to network-wide wireless optimizations;
- new software functionality can be incorporated into the entire network as new protocols are introduced, ensuring rapid time to market;
- uniform O&M support gives consistent handling of routers;
- uniform and comprehensive information is available to management systems, which facilitates the use of powerful tools; and
- interoperability and stability are ensured.

From the start, the protocol suite was developed for both IPv4 and IPv6 networking. That is, the structure has been optimized for handling either standard, and features transition mechanisms between the two. To work successfully with IPv4 and IPv6, some protocols require special handling. The aim has been to support either standard equally well, and to allow the network operator to decide which one (or both) will run in the network.

Another strong feature of the software is that it meets stringent security requirements; for example, it supports IPsec in combination with advanced and updateable encryption and authentication algorithms.

Real-time router management

General approach

In IP-based networks, embedded and standalone routers provide a horizontal network layer service to all involved nodes. In terms of management, this network layer constitutes a logical whole that is managed independently of other parts and services (for example, the radio resources) of the network. This approach benefits the operator in several ways:

- the same systems and procedures for managing IP resources and nodes can be applied to radio-access and core networks, thereby creating a single IP network;
- simplified end-to-end monitoring of QoS parameters (packet loss and so forth) over the access and core networks; and
- the separation of radio and transmission resource management creates an efficient division of labor and reduces training costs.

Where the real-time router is embedded in a node, it shares some resources and information with other subsystems. The implementation allows the operator to configure how this is handled; for instance, how alarms relating to the shared hardware platform should be filtered and correlated.

Element and IP layer management

The management solution for the Ericsson real-time router consists of an element manager and an IP layer manager. These products were designed with the following key principles in mind:

- minimization of O&M costs;
- optimum control of network performance;
- comprehensive support for network planning and optimization;
- highest level of security; and
- open, industry-standard interfaces.

IP layer management

A great number of routers must be used in wireless networks. To reduce the costs associated with setting up and configuring these networks, Ericsson's engineers have designed an advanced network configuration management system (NCMS) that uses an intuitive graphical user interface (GUI) together with the latest LDAP/DEN technology for the automatic configuration of routers. Configuration data is entered at a central location, after which affected nodes are instructed to fetch new configuration data from a central server. In this way, a comprehensive job, such as that of changing a network's open-shortest-path-first (OSPF) area setting, can be reduced to a minimum of operator commands entered at a central location (Figure 5).

A criterion for deploying packet technology in wireless networks is that end-to-end, real-time sessions must be achievable for delay-sensitive applications and signaling. At the same time, businesses and other premium users will conclude service-level agreements with operators, to obtain prior-

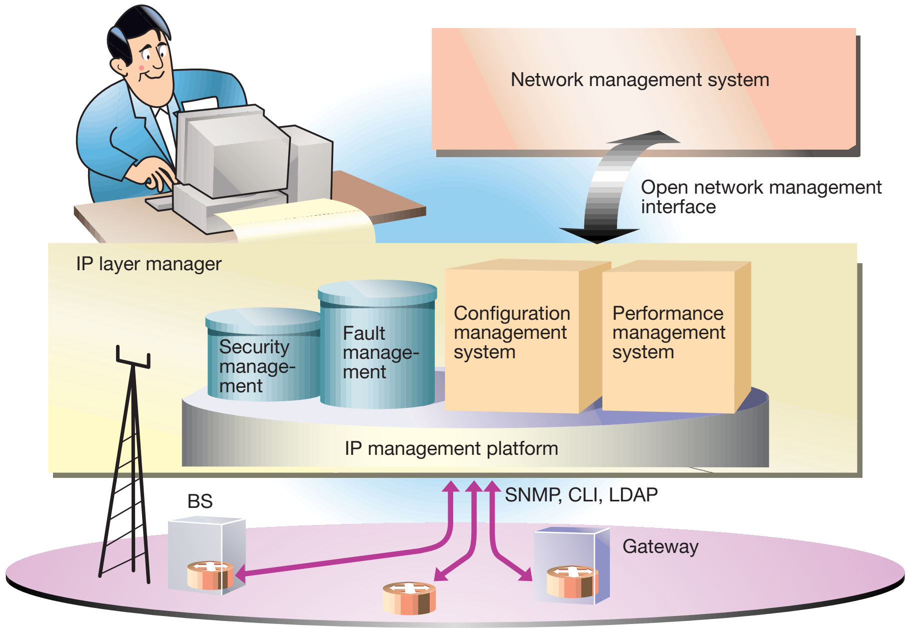

Figure 5
Operators enter configuration data at a central location. Affected nodes are then instructed to fetch new configuration data from a central server. In this way, a comprehensive job can be reduced to a minimum of operator commands.

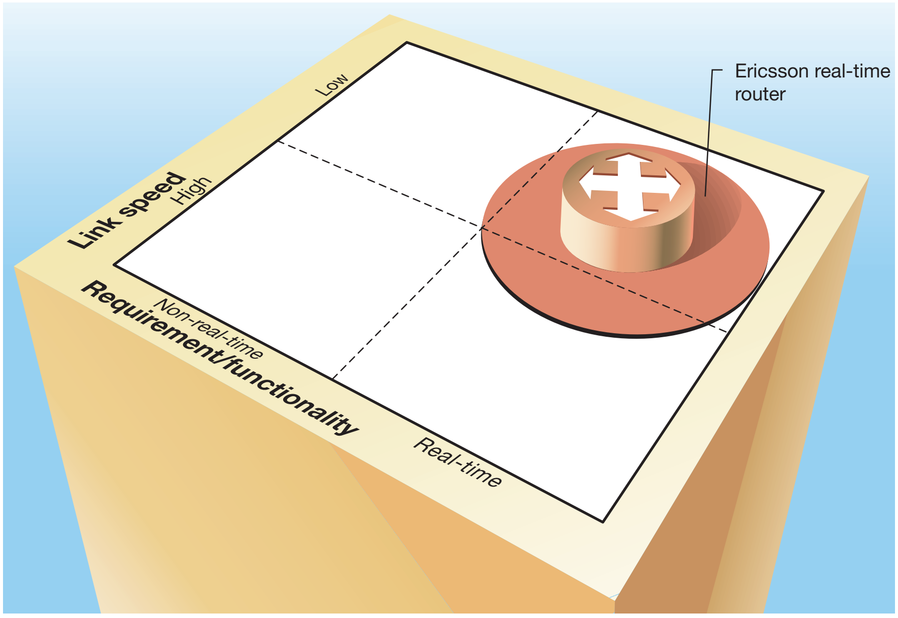

Figure 6
Positioning of Ericsson's real-time router.

ity treatment in the network. In each example, a sophisticated means of monitoring network performance is needed.

Ericsson's software developers designed the network performance management system (NPMS) to collect statistics from the network using standard SNMP and remote-monitoring management information bases (RMON MIB). Once collected, this information is employed to generate performance-related alarms and to serve as the basis for a wide range of powerful offline tools with which the operator can

- evaluate congestion levels on individual links;
- evaluate network-wide performance for DiffServ classes;
- differentiate payload trends from periodic or *ad hoc* congestion;
- obtain an overview of route choices and potential connectivity problems per traffic flow;
- evaluate "what if" conditions by simulating the introduction of extra routers and links, configuration changes, and link or node failure; and
- apply different network-optimization algorithms to determine the best configuration.

If offline analyses and modeling identify a new optimum configuration, the network can automatically be updated thanks to the integration between the network performance management system and the network configuration management system. Each of these systems will also be able to manage other vendors' nodes, provided the nodes comply with industry standards.

Element management

The real-time router implements SNMPv3. This newly standardized version of the simple network management protocol contains authentication and access control enhancements that make it possible to configure the

BOX C, WIRELESS COMMUNICATION-RELATED INITIATIVES IN THE IETF

Ericsson (sometimes in cooperation with other companies) has actively contributed to the IETF, to ensure that the standards issued by that body will evolve in a direction that facilitates all-IP solutions in wireless networks. The most important proposals include:

- Real-time Traffic over Cellular Access Networks[2];
- Load Control of Real-time Traffic[3];
- Requirements for Mobile IP from a Cellular Perspective[4];
- Robust Checksum-based Header Compression (ROCCO)[5];
- A Framework for Differentiated Services[6];
- Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers[7]; and
- An Architecture for Differentiated Services[8].

router in a secure way. The application of IPSec to management traffic may further enhance security. Moreover, different users can be assigned different privileges, and the signing and logging of events makes it possible to trace measures.

The element manager, which is a thin-client Java implementation that resides on the router itself or on a separate server, can be downloaded to any Java-enabled HTML browser. Using the router's SNMP interface, the element manager provides task-oriented GUIs for most configuration tasks. The router may also be configured using the command line interface, either over Telnet or at the console. The CLI, which provides the same level of security as SNMP, uses industry-standard commands and supports extensive scripting.

As stated above, the real-time router supports LDAP, which when assisted by services such as the dynamic host configuration protocol (DHCP) and file transfer protocol (FTP), enables the router to fetch image and configuration files from designated servers. Thus, all software-related tasks (upgrades, configuration changes, and so on) can be handled remotely and with a minimum of human intervention. This also applies to the software settings of the forwarding engines.

Relevant, standard management information bases are implemented for performance monitoring. In addition, a subset of the RMON MIB enables the supervision of local thresholds without the polling overhead associated with conventional SNMP monitoring. The element manager also supports advanced fault management using standard SNMP traps.

Conclusion

All-IP networking offers several operator advantages. However, to realize these advantages in wireless networks, advanced, real-time routers must be installed to satisfy the special needs of transmission equipment in the networks.

Ericsson's real-time routers are unique in two respects: they have been designed specifically to meet the requirements of the wireless environment, and that they will be available as embedded parts of other nodes as well as stand-alone products. To the customer, this means that the same components (interfaces, processors, and switches) can be reused for embedded and stand-alone routers, which lowers maintenance and training costs. Similarly, operators who use the same O&M system for all routers—regardless of their location (as stand-alone or embedded)—can greatly simplify network administration and employ advanced tools for network planning and configuration. Advanced features for automatically configuring the real-time routers further reduces the time and cost of deploying real-time IP networks.

Ericsson's real-time routers support both IPv4 and IPv6, which means they will support the ongoing expansion of the Internet into the wireless "always-connected, always-online" era.

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