

# Building a reliable, cost-effective and future-proof fiber optical access network

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The uptake of broadband services among residential and small- to medium-sized businesses is being helped by developments designed to relieve capacity bottlenecks in existing copper-based access networks. Likewise, the falling costs of laser equipment, fiber and cable installation are positioning fiber-optic solutions to overcome this capacity hurdle. The functionality, scalability and widespread understanding of Ethernet technology make Ethernet-over-fiber a strong candidate to become the preferred solution for extending optical techniques straight out to the wall socket. By offering symmetric transmission of 100 Mbit/s or better, Ethernet-over-fiber access networks will enable the delivery of advanced services including IP-based television, IP telephony, and robust, secure, LAN-interconnect services. Given current and emerging Ethernet standards, which address issues, such as priority traffic handling, LAN security, and circuit-oriented provisioning, it is likely that flexible, multipurpose access networks will soon be built entirely on Ethernet technology.

In many countries, more than one-third of the population regularly uses the Internet. Besides tremendous residential usage, the market for small and medium-sized enterprises is growing. Notwithstanding, the development of broadband service markets worldwide is dependent on having access networks that live up to the vision of the *Terabit society*. A true end-to-end infrastructure, including first-mile connectivity from the home and office, is needed to experience the full potential of next-generation services.

## BOX A, TERMS AND ABBREVIATIONS

ATM	Asynchronous transfer mode
CAT5	Category 5 unshielded twisted-pair cable
CATV	Cable TV
DRG	Ericsson's residential gateway
DSCP	Differentiated services code point
DWDM	Dense wavelength division multiplexing
FSAN	Full-service access network
FTTH	Fiber to the home
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet protocol
IT	Information technology
LAN	Local area network
LCS	Local community system
MAN	Metropolitan area network
OSI	Open system interconnection
PON	Passive optical network
PTT	Postal telegraph and telephone
RSVP	Resource reservation protocol
SDH	Synchronous digital hierarchy
SONET	Synchronous optical network
TOS	Type of service
VoIP	Voice over IP
WAN	Wide area network
xDSL	Digital subscriber line (of any type)

Many large companies already use high-capacity fiber-optic access networks, but small businesses also want to benefit from services, such as e-business, Web-hosting, high-quality video and audio conferencing, and multimedia virtual customer contact centers. Whereas capacity in backbone and metropolitan networks is virtually unlimited, thanks to the widespread penetration of dense wavelength division multiplexing (DWDM) technology, the transmission bottlenecks in the first mile of connectivity are hampering the uptake of these kinds of services.

Fiber is the most effective medium for bridging this gap. Direct fiber connections are an increasingly popular way of delivering broadband services to high-density clusters of users, for example, in business parks and apartment blocks. Fiber has the advantage of almost limitless capacity as fiber-optic networking technology advances. But as yet, availability is limited, and the industry is still awaiting agreement on a common standard.

Although fiber offers perhaps the greatest potential as an access medium, it must be emphasized that all current high-capacity "broadband" access solutions (including xDSL, microwave and cable) have important roles to play, especially in managing a smooth migration from legacy networks to the all-fiber-optic network of the future. The combined force of these broadband technologies will drive market demand and application development. As the services grow and mature, the full strength of fiber-optic solutions (symmetric, secure, and reliable high-capacity connections) will become self-evident.

## Sweden—a broadband pioneer

Historically speaking, it has been prohibitively expensive to build a new, single-service, physical network to replace a network already in operation. Often, the high cost has been further exacerbated by a lack of long-term planning that would have helped mitigate short-term commercial considerations.

Sweden is a notable exception, and one of the leading nations in developing broadband access for all. A theoretical model (Figure 1) of a ubiquitous access network set out in a paper from the Swedish ICT-Commission<sup>1</sup>, shares much common ground with Ericsson's working example in Hudiksvall, Sweden. The ICT report states:

“The communications architecture used for the Internet (IP architecture) is one of the factors driving the integration of telecommunication, data communication and video communication. All services, whatever their bandwidth requirement, will be carried by IP-based networks.

“The present IT infrastructure has been optimized for telephone services and will for the most part have to be replaced by a new infrastructure that has been adapted to the IP communications architecture and to the estimated annual doubling of traffic which will follow the development of new services and the addition of new users.”

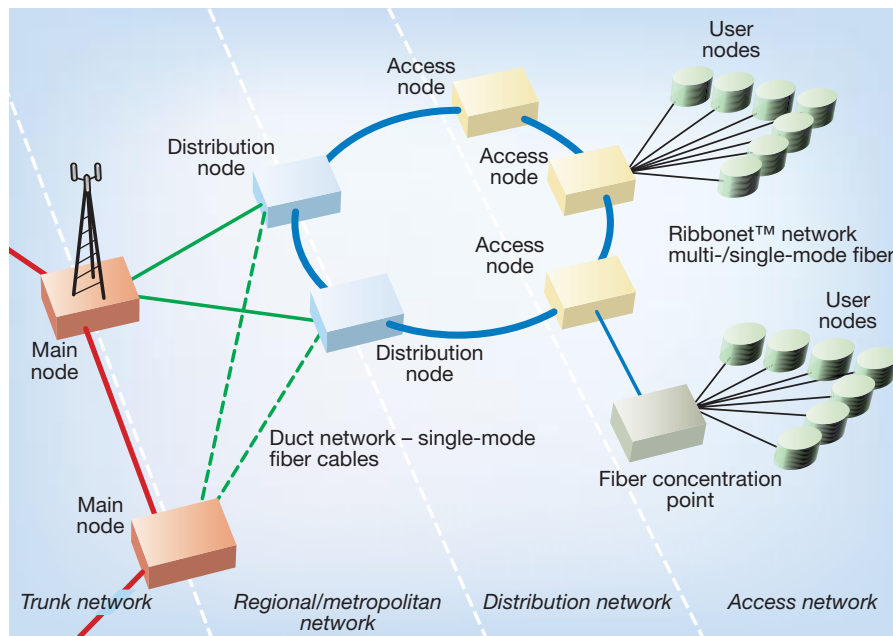
The ICT-Commission envisions a future-proof infrastructure in Sweden:

- In 2005, every household in Sweden will have a fixed Internet connection of at least 5 Mbit/s real throughput capacity.
- By 2005, Sweden should have constructed a fine-meshed fiber-optical network available to all households.
- The network is to be technically and competitively neutral and open to all operators. The aim is to give everyone, through free competition, access to high transmission capacity at low cost.

The new national IT infrastructure is to consist of a fine-meshed fiber network that offers redundancy and the ability to distribute traffic load. Several operators should be able to use the IT infrastructure simultaneously—that is, operators will have access to their own fiber pairs, so as to be able to build their own network structures (for example, star or ring networks). Among other things, this means that parallel network structures will be established using the same fiber cable.

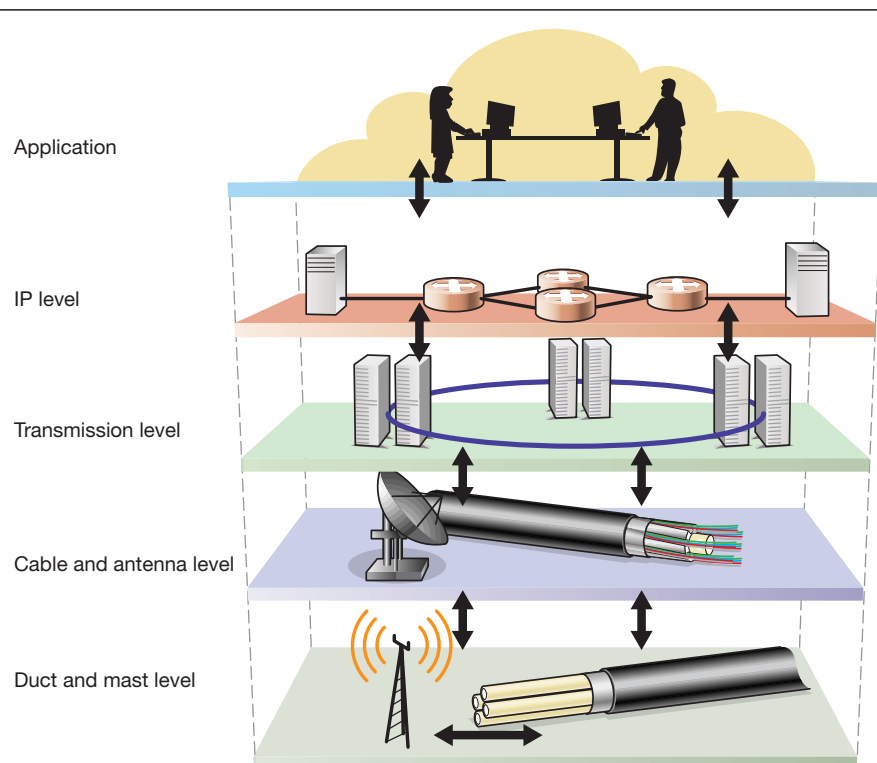
The national fiber structure will thus have to be built in the form of a grid between main nodes that constitute centers of local and regional fiber networks. Communication will be based on IP, which means that data can find the best path in a network, assuming that alternative paths are offered. Redundancy is therefore needed between the main nodes in a municipality and between municipalities. A layered network infrastructure (Figure 2) offers a useful model for realizing this vision.

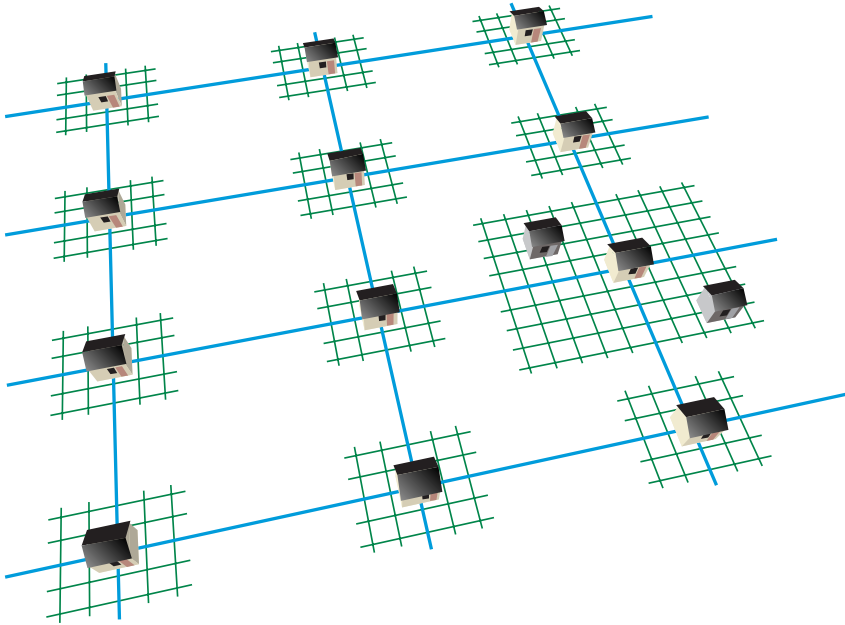
A guiding principle is that the infrastructure must be planned as a general network, and not as a specialized network based on rigid technical solutions or built for a limited number of operators. A general conduit network, containing redundant fiber, can be planned as the basis for carrying competing operators' active networks.



**Fig 1**  
The proposed IT infrastructure.

**Figure 2**  
The levels of the IT infrastructure.

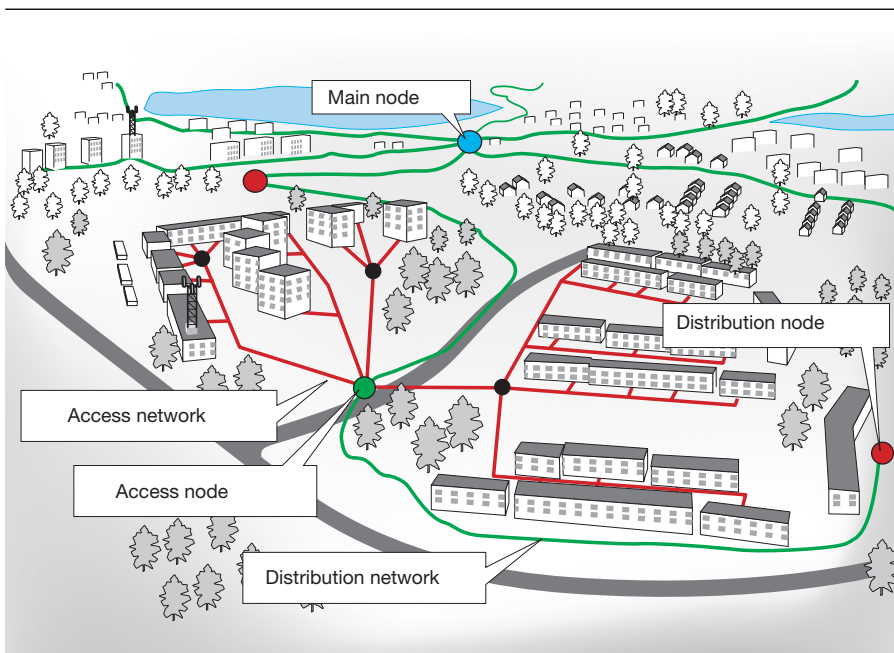




**Figure 3**  
The fine-meshed network with main nodes.

The trunk network (Figure 3) links the main nodes. The requirement of redundant connections must be taken into account at an early stage of development. The main node is the central place for fiber connection. Distribution nodes are connected to main nodes

**Figure 4**  
The physical network.



through the regional/metropolitan network. Each main node serves roughly 20,000 - 30,000 households, enterprises or other organizations within the area. Large cities need several main nodes, whereas smaller municipalities can share a main node with a neighboring community.

Full redundancy is planned between main nodes: one main node is connected to several other main nodes to allow alternative transmission paths. The trunk network and the main nodes are subject to stringent security criteria. The main node might also include the service providers' active equipment.

The regional/metropolitan network links main nodes and distribution nodes in a locality. In municipalities that lack sufficient demand for a main node of their own, at least one distribution node will be connected to the national main network through a main node.

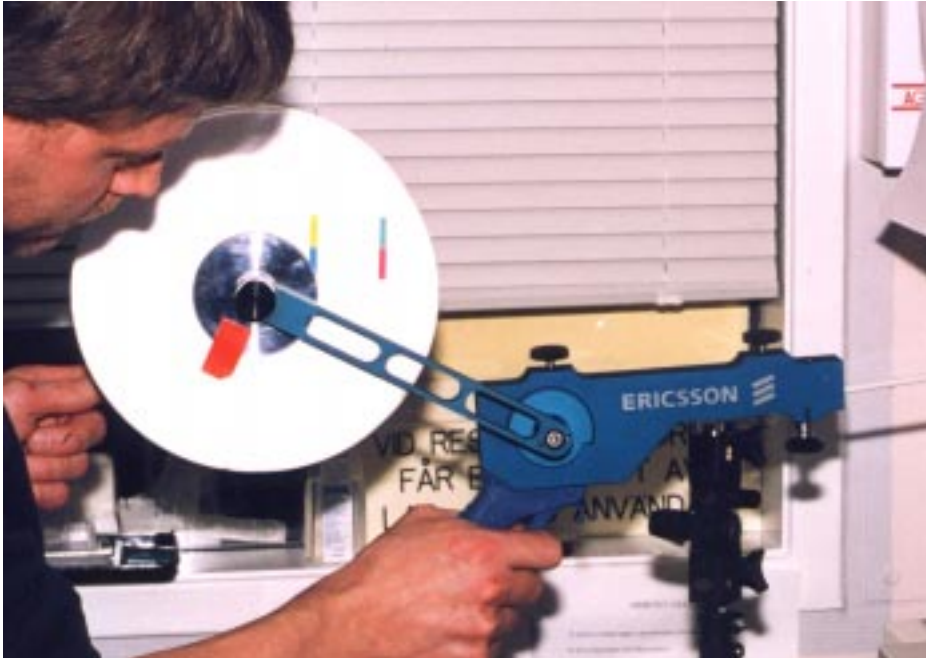
The distribution node is primarily a passive cross-connection point at the fiber level within the area. Even so, the distribution node must be designed in consensus with all operators to take into consideration the placement of active equipment. To achieve redundancy, the distribution node should be connected through different links to two different main nodes. The distance between the distribution nodes will vary in proportion to population density.

The distribution network, which comprises the connection between distribution nodes and access nodes, consists of a loop that links access nodes with two distribution nodes. The access node and distribution node can be co-located depending on the design of the distribution network.

A network built within a building is called an access network and is connected to the access node. An access network can comprise anything from a network within a building to networks in and between several buildings—for example, campuses, hospitals and industry parks.

## From theory to practice—the Hudiksvall broadband island

The vision of nationwide broadband availability is already becoming a reality, as illustrated by a pilot project in Hudiksvall, Sweden conducted in a joint venture between Ericsson and Hudiksvallsbostäder AB (Figure 4). The project is based on the con-



**Figure 5**  
Fiber blown into the Ribbonet microduct using patented blowing tool.

cept of broadband islands—a network that delivers services from a number of providers with national and local presence. The aim of the project has been to build a high-capacity broadband network that offers fixed, symmetrical, high-speed Internet access suitable for home entertainment, small businesses, home-based working, schools and hospitals. To be prepared for emerging services, such as IP-based TV distribution, IP telephony, and other, yet undefined services, the access network delivers a capacity of 100 Mbit/s to each apartment.

The access network is based on an active star topology (a fiber-pair to each end-user whether actively connected or not) that radiates from a centrally located access node. Fibers are blown through an installed microduct system from the apartment to the access node, which is directly connected to the distribution network with a capacity of 1 Gbit/s. This capacity is shared by all users within the network area. Several areas are connected to the main node, which has a switching capacity of more than 100 Gbit/s. All apartments are connected to the access node by blown-in multimode fibers (Box B). Tenants that subscribe to broadband services are connected by a switched Ethernet network that operates over the multimode fiber connection. Initially, the network gives symmetrical access at 100 Mbit/s. Later, the network can be upgraded to Gi-

gabit capacity by changing end-user and access node electronics. The installation described here is based on the Ericsson Ribbonet system.

## The transmission layer – Ethernet-over-fiber

The choice of transmission technology is every bit as important as having a resilient and future-proof physical network. Carriers and service providers want stable solutions that are also flexible enough to accommodate a rapidly changing landscape. Ethernet-over-fiber meets these criteria and

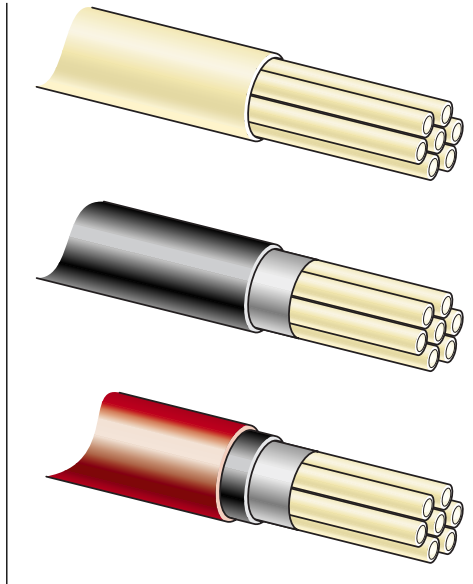
### BOX B, THE ERICSSON RIBBONET SYSTEM

A basic requirement throughout the project in Hudiksvall has been to minimize the cost of fiber installation, so that the passive parts of the network do not cost more than a CAT5 copper network. Innovative techniques have reduced costs and sped up the installation process. Ribbonet, for example, is a complete system developed by Ericsson that comprises a lightweight, compressed air-driven blowing device (Figure 5), microducts (Figure 6), fiber-distribution fields, fiber-optical cables and pre-terminated fiber-pairs. The system prevents potential damage caused by pulling cables,

and saves time since no intermediate fiber splicing is required for point-to-point connections. One intermediate splice is needed if fiber concentration points are used (Figure 7).

Other benefits of the blown-fiber approach are that damaged fibers can be replaced quickly and multimode fibers can be replaced with single-mode fibers for certain routes. In cases where service must be deployed in stages, network builders can initially install a conduit network (empty microducts) to user premises. Later, fiber can be blown in more or less on demand.

**Figure 6**  
Ribonet multi-microducts (indoor use, top; outdoor use, center; direct burial outdoor use, bottom). Available in combinations of up to 24 single ducts.



is poised to become the preferred access solution in part thanks to its functional flexibility and low cost, and in part to widespread knowledge and acceptance of the underlying technology. As a consequence, the IEEE is working on a standard for Ethernet in the first mile: the standard, IEEE 802.3ah, is scheduled for completion by 2003.

Likewise, a group of equipment manufacturers is currently developing a solution it calls Ethernet passive optical network (PON). The solution is largely based on previous work within full-service access networks (FSAN), which standardized ATM PON. PONs use point-to-multipoint topology with passive optical splitters, to eliminate active electronics (regenerators, amplifiers, and lasers) in the access network. This can also be achieved with long-reach active optics, but the corresponding PON topology can reduce the number of outgoing fibers and lasers needed at the active distribution point (for example, at the central office).

PONs are effective at delivering services that require large bandwidth, such as analog video distribution and fast Internet access, but they do so in a technically complex manner with little or no flexibility for future upgrades and network expansion. Also, due to their asymmetric nature, PONs do not adequately serve the needs of users who request equal upstream and downstream connectivity.

Ethernet-over-fiber active access networks overcome most of the limitations as-

sociated with PONs. The falling cost of optical components has largely eliminated the cost benefit of deploying asymmetric passive systems in favor of symmetrical active solutions. An active access system—with a symmetrical infrastructure of transmitters and receivers at each end of the connection—is a proven platform for distinct and differentiated services, and a cost-effective and flexible basis for next-generation access solutions.

Ericsson's Ethernet-over-fiber access solution sets out to capitalize on all these benefits, building a switched Ethernet infrastructure that is based on low-cost standard components but takes the perspective of a public access network rather than the traditional enterprise networking view of Ethernet. One important aspect is circuit-oriented provisioning: In earlier solutions, subscribers would have a dedicated pair of wires or some other form of leased line that connected them directly to the service provider. In Ericsson's current solution, this objective is moved up to the data link layer. Each subscriber has a dedicated virtual LAN for basic connectivity services, and service providers have dedicated virtual LANs for providing services to subscribers.

Looking above and beyond the access network, Gigabit Ethernet has already established itself as the main alternative for new operators who are building metropolitan area networks (MAN or Metro), since the cost of Gigabit Ethernet is substantially less than that of synchronous digital hierarchy (SDH). Within the next two years, Gigabit Ethernet is expected to become commonplace for enterprise access applications, although not all businesses will require the full capacity supported by this standard.

Over the next few years, 10 Gigabit Ethernet (10GE) will probably emerge as the preferred solution for both MAN and wide area network (WAN) applications, since it provides adequate capacity and supports greater reach than all previous versions of Ethernet. Incidentally, unlike its predecessors, 10GE is also the first purely optical Ethernet standard.

## Maturing Ethernet standards

Innovations in two main areas are driving the development of optical access networks:

- structured optical cabling systems, with new and efficient means for installation; and

- advanced, low-cost optics, such as optimized components from the Ethernet world—these yield cost-effective optical solutions that are suitable for deployment in the access network.

Regarding the transmission (or physical) and data link layers, maturing Ethernet standards comprise the single most important enabler of advanced new access networks that offer high capacity at low cost. In terms of functionality, recent and emerging standards are introducing features such as priority traffic handling, virtual LAN-based security, and improved network-management mechanisms, which means it may soon be possible to design flexible, multipurpose access networks using only Ethernet standards.

Full-duplex switched Ethernet (IEEE 802.1D and 802.3x) gives full-speed, two-way, point-to-point links with no collisions, and theoretically, no distance limitations. The addition of the appropriate implementation of switch nodes creates a flexible and powerful network with large throughput, limited overhead, and minimal end-to-end latency.

Likewise, the addition of priority traffic handling (defined by IEEE 802.1p) and switch hardware port queues, supports fine-tuned, differentiated traffic classes for opti-

mal support of diverse applications. Finally, the use of IEEE 802.1Q virtual LANs for circuit-oriented provisioning and privacy, yields a fully functioning access solution built purely on standard Ethernet features.

For full-fledged broadband access, a few additional features are needed, but these are already available in many Ethernet switch implementations and will probably be included in the future standards suite. Among these features are bandwidth-provisioning mechanisms, managed delay and jitter bounds, traffic volume and flow counters, and enhanced virtual LAN management capabilities. Most of these features are currently included in Ericsson's local community system (LCS).

## Ericsson and Ethernet-over-fiber

The Ericsson LCS, which is a consistent and integrated Ethernet access network optimized for dedicated fiber infrastructure and Ribbonet, enables large, symmetric bandwidth to each connected user and supports differentiated service level agreements and quality of service. Originating from the broadband island concept, LCS builds access connectivity almost entirely on data link layer (Layer 2, L2) switched Ethernet with

**TABLE 1, COMPARISON OF ETHERNET STANDARDS AND COMMON EXTENSIONS**

TYPE OF ETHERNET	STANDARD	REACH	DESCRIPTION
Fast Ethernet, 100Mbit/s MMF 100Base-SX	EIA/TIA standard	300 m	Formerly used in Ericsson local community system (LCS, see below)
MMF 100Base-FX	IEEE standard	Up to 2 km	Used for final drop in Ericsson LCS
SMF 100Base-FX	Not an IEEE standard, but vendor-specific implementations are available	Standards proposals (for example, 10 km) made to IEEE 802.3ah	Not currently included in Ericsson LCS, but feasible
<b>Gigabit Ethernet, 1Gbit/s</b> MMF 1000Base-SX MMF 1000Base-LX	IEEE standards for short range	<550 m	Option: available with Ericsson LCS
SMF 1000Base-LX	IEEE standard specifies only	5 km (10 km <i>de facto</i> standard) Less common extensions are 40 km, 70 km, 100 km	5-10 km and 70 km offered with Ericsson LCS



**Figure 7**  
Ribbonnet duct-/fiber-jointing cabinet for outdoor use, for example, in residential areas.

100 Mbit/s full-duplex user gross data rate. The system has been designed primarily for providing IP-based services with a guaranteed quality of service. However, LCS is also a transparent access network for enterprise users who need native Ethernet LAN connectivity for private data networking.

LCS is modular, flexible and scalable, with a network topology that can be adapted to almost any physical, fiber-based access infrastructure. It uses a dedicated fiber pair (it can also use copper CAT5 connections) from customer premises to an initial aggregation point that houses an Ethernet switch node. At present, these connections are multi-mode, but single-mode connections are foreseen in the future, enabling much longer fiber runs from (or to) the home.

The use of switching and virtual LAN technology makes LCS a circuit-oriented Ethernet access network and a versatile platform for providing IP-based services. Virtual LANs are employed to separate and segregate users and private networks, differentiated services, and access network elements. In this way, a robust foundation for user integrity and network security is established without making use of routing in the access network.

As mentioned above, individual service providers have one or more dedicated virtual LANs for providing differentiated services to their subscribers. For service providers connected to LCS on L2 Ethernet—that is, in cases where no intermediate routing is involved, end-to-end provisioning is completely transparent. This kind of transparency is considered a key property of next-generation access networks, since they are completely neutral and open to connection from any kind of service from any service provider. However, because not all kinds of service are currently suited for pure L2 end-to-end provisioning, the Ericsson LCS can also use higher-layer protocols. At the point where the L2 traffic domain is terminated, LCS L2 provisioning needs to be mapped to higher-layer provisioning mechanisms. A typical example is voice over IP (VoIP), since the media gateway might be situated far away on a routed WAN. In this case, IEEE 802.1p priorities are transferred to and from IP TOS/DSCP, and possibly RSVP.

In its default configuration, LCS also touches Layer 3 (OSI network layer) and higher-layer protocols for augmented IP multicast performance, and to block out spoofing and denial-of-service attacks. With regard to functionality that can be implemented on either L2 or L3, Ericsson's LCS solution adheres to the following guidelines:

- Although services can be provided more or less entirely on L2, such a scheme requires capable access termination equipment at customer premises. In its basic configuration, the Ericsson LCS includes a less capable device with no advanced L2 features, rendering lower cost per customer connection. In this configuration, most services are provided on L3 and L4, and consequently, most of them terminate in users' devices.
- When the Ericsson LCS is configured for VoIP dial tone, more sophisticated access termination equipment is needed—that is, additional L2 functionality is required in the user premises equipment (the Ericsson DRG). In this case, most of the service provisioning is moved down to L2 and controlled in the L2 access network, efficiently enabling specific quality of service.

## Toward the all-optical network

With these solutions available today, an optical network should be the obvious choice

### TRADEMARKS

Ribbonnet is a trademark owned by Ericsson Network Technologies AB.

for greenfield installations or refurbishing. Interestingly, with an annual refurbishing rate of 5-10% of a network, all-optical technologies will also dominate the access network in just a few years. However, the physical infrastructure in fixed public access networks tends to last longer than any other fixed communication infrastructure. This is primarily due to the immense quantities of cable and labor involved in building the networks.

Given the large base of legacy access networks, and that much of the deployment cost of fiber networks is determined by the cable installation, efficient migration strategies are needed. At some point, a decision to move from a coaxial access network to an optical fiber network will inevitably involve ripping up old plant and installing new fiber. However, the associated costs can be mitigated by adopting a mix-and-match approach. All-copper networks can be updated using a hybrid solution, where, for example, fiber is taken to the roadside, and individual customer connections remain on coaxial cable. Commercial considerations will determine how far an operator will take the fiber installation, but when demand makes it feasible, the ultimate goal—of replacing remaining copper and of having an all-optical access network—can be achieved.

As in all effective migration strategies, key factors are to balance investments in new equipment with the capabilities of existing infrastructure, and to stay one step ahead of market demand while building a foundation for generating future revenues. For example, a PTT migrating from narrowband over a twisted-pair connection might implement an Ethernet-over-DWDM solution in the metropolitan network in combination with Ethernet-over-VDSL in the access network. By the same token, a CATV operator moving from analog broadband to digital broadband-over-fiber might first implement Ethernet-over-cable before having to invest in a new optical fiber access network. Note that both of these examples build on early inclusion of Ethernet access technology, and pave the way toward a future all-optical Ethernet infrastructure.

The introduction of optical edge multiplexers will be an important factor in managing a smooth migration strategy. Optical edge multiplexers provide optical gateways that perform a mixture of electrical and optical transmission (for example, IP carried over Ethernet, ATM and SDH/SONET) and convert and combine traffic into suitable op-

tical formats for onward transportation. Optical edge multiplexers will enable legacy technology to be reused as part of the new generation of converged, multiservice networking infrastructure. They will be built on thin SDH/SONET technology, which is to say that bandwidth will be managed in small chunks (50–150Mbit/s). With scalability a prime concern, the edge multiplexer will be designed to handle virtually all expected growth.

Gigabit Ethernet is becoming increasingly popular for metro and access solutions. It is particularly suitable for enterprise LAN and FTTH applications thanks to simplicity and cost benefits compared to alternative solutions based on ATM and SDH.

Most probably, in the end we will see a variety of complementary solutions for the access network. Operators focused on IP/LAN services may opt mainly for 10 Gigabit Ethernet or Gigabit Ethernet over DWDM, whereas telecom and multi-service operators might base their access networks mainly on TDM or TDM over DWDM.

## Conclusion

All-optical access networks are starting to materialize before our eyes. After spending some two decades in feasibility studies, lab and field trials, public access networks based on fiber optics have eventually found their way into product portfolios, and are now becoming ready for deployment at scale.

Advanced optical backbone networks are continuously helping to prove the viability and potential of optical technologies, and providing innovations leading to improved components. The cost-sensitive public-access application benefits from this development, as optical transmission technologies mature.

The synthesis of cost-effective fiber optics on the one hand, and simple and efficient networking technology from the Enterprise LAN segment on the other, has resulted in Ethernet-over-fiber access solutions with unprecedented capacity and cost-effectiveness. The amendments required to optimize optical Ethernet networks for large-scale public access are largely in place today, and the rest is underway. The result is a ubiquitous infrastructure for IP-based communication, reaching out to connect any and every end-user, and carrying any kind of traffic.

## REFERENCES

- 1 Swedish ICT-Commission, Report 37, 2001 (available at [www.itkommissionen.se](http://www.itkommissionen.se)).