he telecommunications industry is keenly focused on advancing metropolitan-area networks (MANs) into areas where increases in bandwidth demand from local-area/wide-area networks (LANs/WANs) have far outpaced the traditional metro network. The burdening of the metro ring will only worsen as more and more services, including voice, video and more data-centric computing, become part of the mix.

New and next-generation versions of existing technologies, including Ethernet, Sonet and the new Resilient Packet Ring (RPR), have been promoted to carriers as the solution to the MAN bottleneck. But, how does each of these technologies measure up against the non-negotiable requirements of reliability and robustness that today’s carriers and end users demand?

For some, legacy Sonet/SDH networks, augmented by virtual concatenation and the link capacity adjustment scheme (LCAS), are the path of choice. But Sonet has brought with it problems relating to resource utilization and cost. And Ethernet, while offering a low-cost, scalable alternative, still produces poor jitter and latency control.

Though still a work in progress, under the auspices of the IEEE 802.17 RPR Working Group, the new RPR Layer 2 protocol for the MAN and WAN combines the best of both Ethernet and Sonet— with many additions of its own. These additional functions help make it an extremely attractive alternative to either Sonet or Ethernet for the high-speed, convergent, multimedia network. To fully appreciate what RPR brings to the table, it’s necessary to see where legacy networks run aground, then examine in detail the ins and outs of the alternative RPR media-access-control mechanism.

Historically, separate parallel networks have been used to deploy data, voice and video services. However, it has become more efficient to converge the multiple services over a single network. These converged services typically include committed information rate (CIR) services such as virtual private networks and business Internet access; best-effort, consumer-oriented Internet access; voice-over-Internet-Protocol (VoIP); packet video; and time-division multiplexing (TDM) services.

Those services have their own network-performance requirements, which puts designers under extreme pressure to accommodate widely varying degrees of latency, bandwidth efficiency, quality-of-service (QoS) and overall reliability and manageability.

For metro data networks, Sonet and Ethernet have garnered much of the...
attention, with many fiber rings currently deployed as Sonet/SDH networks. Neither technology, however, is optimized for MAN data applications. In the case of Sonet/SDH, customer data is transported over a TDM infrastructure back to the provider. The legacy Sonet/SDH add-drop multiplexer network offers customer access in the form of DS-0, T1 and T3 interfaces, and sometimes Ethernet. The advantages of Sonet/SDH are that it offers good jitter and latency performance, and it is a lossless transport in that packets are delivered from source to destination without any QoS decisions in between. In addition, Sonet/SDH uses spare fibers or capacity to provide protection in case of fiber cuts or equipment failures.

To better suit data applications, Sonet/SDH has implemented improvements such as virtual concatenation and LCAS. Nonetheless, with roots as a phone network, it’s not the most efficient transport as it creates point-to-point circuits. Also, bandwidth is reserved for every source on the ring, meaning other nodes cannot claim unused bandwidth.

Sonet/SDH networks can also be expensive, due to multiple layers of equipment such as routers and switches.

For its part, Ethernet is both cheap and ubiquitous, but it’s not a carrier-class solution as it provides point-to-point connections: At every hop on the ring, a router or switch will process each packet, which can be time-consuming for large rings. As a result, Ethernet will have trouble meeting the jitter and latency requirements for voice and video.

**Resilient Packet Ring**

RPR technology is a new Layer 2 protocol for the MAN and WAN that appeals to carriers and service providers seeking to quickly deploy the newer, profitable services. Combining the advantages of both Sonet and Ethernet, RPR allows the support of the newer services while simultaneously supporting traditional carrier-class features such as resiliency, restoration and QoS.

Standout features of the RPR MAC include a transit path to avoid packet switching, as well as express treatment throughout the network of all marked packets to support jitter- and latency-sensitive traffic. Resilience on a par with Sonet is achieved with 50-ms protection switching, while bandwidth efficiency is achieved by delivering packet services instead of circuits. Bandwidth management gives the flexibility to oversubscribe the total ring bandwidth with a greater number of users for certain (nonguaranteed) services and temporarily reclaim reserved bandwidth from idle stations.

RPR utilizes bandwidth traditionally set aside for Sonet protection and strips data from the ring when it reaches its destination, leaving spare bandwidth to be reused (spatial reuse). This stripping yields a fourfold increase of the effective bandwidth over the equivalent Sonet network. For multicast packets, one packet is circulated to multiple nodes. This is more efficient than the flooding with multiple packets by Ethernet.

For reduced latency, RPR uses dual counter-rotating rings (inner and outer), each carrying working traffic (Fig. 1). To transmit, each station has a topology map to help it choose a ring based on the least-hop count to a destination (or some other cost metric such as distance). Unlike
Ethernet rings, each RPR station will process only the packets addressed to it. Other packets quickly transit through the RPR MAC.

While RPR can be used to replace Sonet/SDH and Ethernet networks, it often works in combination with both. For example, RPR rings using Sonet/SDH optics can be transparently carried within Sonet/SDH transport. This allows carriers to use their current infrastructure to deliver legacy services and RPR for new data-optimized services. With respect to Ethernet, many RPR systems use Ethernet as the subscriber interface and RPR as an uplink (Fig. 2). Ethernet is a cost-efficient interface, which complements the dynamic-bandwidth services that RPR is able to offer.

RPR MAC features

The RPR MAC is currently being defined in the IEEE 802.17 Working Group and its primary purpose is to provide access to the ring media. Each station on the ring contains two MACs to communicate over the two fiber rings. In a typical transaction, the host system will send data and control (topology, protection) information to the MAC control sublayer (Fig. 3). The MAC control sublayer will then send RPR frames to the appropriate MAC for transmission over the physical layer.

Packets received by either MAC will be routed to the host in the case of a destination address match. Other packets will be placed back on the ring to transit toward the other nodes on the ring.

The RPR MAC offers access to four services to the host client:
- Reserved. Unlike the other services, the idle bandwidth for this provisioned service will not be available to other services. This service is similar to TDM circuits.
- High priority. This is for jitter- and latency-sensitive traffic and is not subject to the bandwidth-sharing algorithm. It may be provisioned by the system.
- Medium priority. This service is for CIR and other provisioned bandwidth services for which access to the ring is guaranteed.
- Low priority. The bandwidth-sharing algorithm governs this service. Bandwidth is dynamically negotiated between the multiple stations on the ring. Best-effort Internet services would be a typical application for this service.

In addition to receiving and transmitting packets to and from the host, the MAC has the unique function of a transit path. The transit path allows packets not destined for a particular station to quickly continue around the ring with minimal processing. The host system will not process any transiting packets. For Ethernet and other point-to-point protocols, a router or switch will fully process each packet through the routing or switching engine in order to make a forwarding decision, increasing packet loss, jitter and latency compared with RPR networks. The RPR MAC processes each packet according to the information given in each header (Fig. 4).

Inside the RPR MAC are several prime functional blocks (Fig. 5). Those blocks include the client interface, drop logic, transit path, bandwidth manager, protection, topology and the physical layer. Their functions are as follows:
- MAC client interface. This system interface allows the host to transmit and receive data based on class. Unlike perhaps switched networks such as Ethernet, RPR packets are not dropped at intermediate nodes. The ability to back-pressure the host system ensures that transmitted packets will have bandwidth available to them on the ring.
- Drop logic. The RPR MAC checks the destination address of every incoming packet to determine whether it should be stripped from the ring or placed in the transit buffer. The drop-logic function can perform the following actions:
  - Strip unicast packets from the ring and send them to the host based on a matching destination address.
  - Copy multicast packets to host and place them in the transit path based on a matching multicast destination.
  - Strip bandwidth notification packets and send them to the bandwidth manager.
  - Place packets in the transit path if their destination address does not match.
  - Strip packets from the ring if cor-

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**FIGURE 3:** The MAC-control sublayer chooses the appropriate MAC to transmit data from the host to the ring. Incoming packets are routed to the host or placed back on the ring.

**FIGURE 4:** The RPR MAC processes each packet according to the information given in each frame header.
The bandwidth manager allows spatial reuse, giving up to a four-fold increase in total ring capacity.

- Protection. The RPR standard requires a 50-ms protection mechanism, using steering (the default) and wrapping. With steering, all nodes are notified to avoid failed spans by utilizing the other fiber. With wrapping, traffic will be directed to the opposite fiber by nodes adjacent to the failed span.

- Topology. The topology-discovery process collects station addresses and maps them in the order of their ring location. RPR will automatically choose the best path to a destination on the ring. This topology map is also available to the host client, allowing the host to choose the path a packet takes.

The topology map is updated at regular intervals and after protection events. This automatic process relieves the host from having to announce its presence and slowly learn the presence of others on the ring.

Sonet/SDH relies on central management to configure the network topology. Ethernet switches can learn their topology by monitoring the stations where packets have been detected on their ports.

- Physical layer. RPR will use existing physical-layer solutions, including existing framers and optics. And because the RPR stations transmit asynchronously on the network, there is no need for timing synchronization between RPR and the chosen physical layer.

The IEEE 802.17 RPR Working Group is in the process of developing a reconciliation layer that will support packet-over-Sonet (POS)- and generic framing procedure (GFP)-encapsulated Sonet and Ethernet physical layers. Final approval of the IEEE 802.17 standard is expected in mid-2003. Although the protection-switching mechanism works independently of the physical layer, it will use the Layer 1 fault monitoring available with Sonet or Ethernet (Gigabit Etherenet and 10-Gigabit Ethernet).

The working group will also define a reconciliation layer that will allow the MAC to interface to currently defined physical-layer interfaces such as SFI, XAUI and XGMMI. Operations, administration and maintenance, to be used for network management, will also seamlessly support either Sonet or Ethernet transport. The MAC definition will include the counters and registers required to collect the statistics to monitor overall network performance.

For related discussions see:
“Digging Into the RPR Spec,” www.commsdesign.com/story/OEG20020410S0004

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