Technical Whitepaper

Optical Flow Networking

A Foundation for the Next-Generation Optical Internet

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"Driving the Intelligence of Packets into Waves"

Optical Flow Networking

A Foundation for the Next-Generation Optical Internet

Overview

Village Networks introduces a breakthrough solution for service providers' next generation Optical Internet – *Optical Flow Networking*℠.

The prevailing industry wisdom is that the next generation Internet must provide not just bandwidth, but *intelligent* bandwidth to deliver the quality, performance and reliability required by the advanced IP-based applications being demanded by e-commerce enterprises and end-users. In order to deliver these high-value IP services to their customers, the service providers' challenge is to find the right solution for their next-generation Internet – one that is scalable and reliable, while providing optical-speed QoS-based bandwidth control.

Village Networks' Optical Flow Networking (OFN) is a new, unique networking technology that solves the problem of delivering optical-scale bandwidth intelligence. The OFN technology tightly integrates light-speed packet processing with multi-wavelength optical switching in a single networking device. This breakthrough enables service providers to obtain complete visibility and control across optical and IP networking domains, achieving new levels of network performance and reliability not possible with multiple, discrete devices.

Optical Flow Networking provides:

- Flexible, dynamic packet-over-lightpath bandwidth creation and management for maximizing network resource utilization.
- QoS-based packet forwarding and control at optical rates for achieving optimal network performance.
- Topology-independent (ring or mesh) packet-over-lightpath service restoration that is fast and efficient for insuring fail-safe, reliable networking.
- Scalability that dynamically matches optical capacity with electronic processing for long-life network application.
- Simplified network planning and management of IP over multi-wavelength optical networks.
- Substantially reduced network equipment and operational costs.

Village Networks' OFN solution addresses the immediate service provider challenge of scaling the network for rapid, reliable, and intelligent bandwidth delivery for IP over multi-wavelength optics, and lays the foundation for the next-generation Optical Internet.

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Introduction

The dramatic growth of the Internet has made it imperative for service providers to seek higher speed, higher capacity networking solutions – high-end IP routers on the one hand, and "*light-speed*" optical switches on the other – for building their next generation IP network infrastructure. This direction is based on prevailing industry wisdom that a next-generation Internet must provide not just greater amounts of bandwidth, but also "intelligent" bandwidth, enabling service providers to offer high-margin, next-generation IP services with the performance, reliability and scale characteristic of today's switched voice network. However, until the intelligence IP-enhanced quality of service (QoS) capabilities can be delivered at light-speed, service providers will not be able to take advantage of the promise of optical networking for building the next-generation Optical Internet.

In response to this challenge, many equipment providers are focusing on developing either high-speed optical networking systems or high-capacity IP routers. Implementation agreements or industry standards are subsequently being pursued for interconnecting routers and optical networks, essentially creating the "*glue*" between IP intelligence and optical capacity. This "glue" has yet to be fully defined. Its definition raises several interesting questions:

- How fast should its packet processing rates be?
- How many protocol layers should it include?
- Should it embrace both switching and transport?
- How soon can it be brought to market?

Village Networks answers these questions with a unique approach called *Optical Flow Networking*[SM], whereby IP intelligence is highly integrated with the optical domain using a single device. This blend achieves new levels of intelligent bandwidth control, performance and reliability not possible with multiple, discrete components – even those of very high performance.

The following pages describe 1) the business problem that OFN addresses, 2) current approaches to solve this problem, 3) why most current approaches are deficient, and 4) details of the OFN technology and architecture. Most importantly, this paper addresses how Optical Flow Networking benefits service providers in building their next-generation Optical Internet.

Service provider Market Opportunities and Challenges

Enterprises and end-users continue to expand their use of IP-based collaborative services and applications, including the addition of mission-critical applications. In doing so, users are funneling more and more traffic types onto their IP networks. As congestion grows and bottlenecks form, they have begun to recognize the critical need for enhanced traffic management and QoS options from their service providers (SPs). The SPs realize that in order to remain competitive, retain their customers and deliver high-margin services, they must in turn be able to offer:

- Stringent service level agreements (SLAs) with guaranteed QoS options.
- 99.999% network availability.
- Rapid provisioning of service.
- Real-time response to customer problems and move/add/change requests.

These services must be provided with networks that are easily scaled, efficiently managed, and designed to accommodate growth while driving networking costs down.

Service providers face significant opportunities and risks. Recent studies[1] highlight the fast-moving trend towards high-value IP connectivity services such as VPNs, and the increasing focus on IP QoS and MPLS to support services such as VoIP and other performance-sensitive applications. A study by Infonetics Research is forecasting a greater than 500% increase in enterprise VPN spending through 2004 to almost $40 billion from its $6.3 billion level in 2000. Similarly, the VoIP market is projected to grow to as high as $91 billion by 2006.

With opportunities come challenges. Service providers must successfully navigate:

- *Bandwidth scalability*: Keeping up with IP traffic growth while maintaining profitability is clearly one of the biggest problem carriers face. If predictions of exponential growth in IP traffic hold true, a network 100 times the size of today's voice network will be required, with voice traffic volumes relegated to a less-than-1 percent share in an IP-dominated network.
- *Intelligent bandwidth control and management*: Controlling and managing network bandwidth with intelligence will require SPs to devise methods for allocating network resources, controlling bandwidth requests, and routing traffic while guaranteeing QoS.
- *Network reliability*: Assuring a 99.999% level of service availability, even during periods of network faults or congestion, is a stringent requirement for today's mission critical applications.

With such opportunities and challenges facing service providers, it is critical to select the best technology and architecture for building their next-generation IP infrastructure.

Current Approaches for the Optical Internet Architecture

Several approaches are under consideration for meeting the challenges of network bandwidth scalability, intelligent bandwidth control and network reliability. The predominant architecture used in today's core IP network architecture consists of four layers (see Figure 1): IP for routing, ATM for traffic engineering & QoS, SONET/SDH time-division multiplexing (TDM) for transport networking & restoration, and DWDM for physical-layer transport & expansion of fiber capacity. Bandwidth in this environment

[1] *Data Networking: IP Switching &Routing*, Merrill Lynch, February 13, 2001

is managed at four distinct levels with different granularities: IP packets, ATM cells, SONET/SDH frames, and DWDM wavelengths.

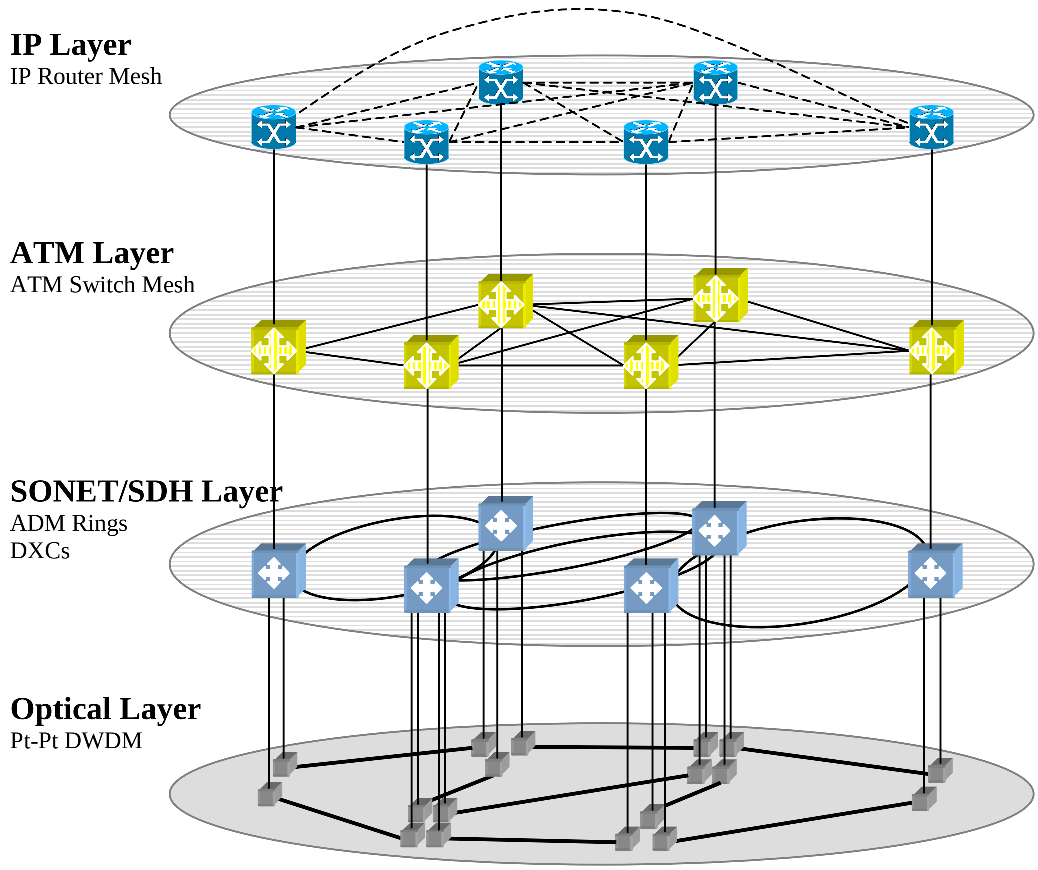

Figure 1: *Four Layer Model – Impractical for Next-Generation Optical Internet*

Although the four-layer model has been adopted for today's IP network infrastructure, this solution has significant disadvantages in terms of bandwidth scalability, intelligent bandwidth control and reliability. DWDM provides a solution for bandwidth scaling, but it only creates a set of point-to-point, high-capacity links that do not incorporate the IP intelligence for network scaling, control and restoration. Internetworking IP routers on DWDM links using SONET/SDH add/drop multiplexer (ADM) or digital cross-connect systems is no longer practical given that IP routing is now often performed at optical rates (OC-48c/192c).

The use of ATM switches for traffic engineering now becomes irrelevant in the core or core edge where the number of IP trunks approaches the granularity of wavelengths. With advances in IP-based specifications like Multi-Protocol Label Switching (MPLS), IP traffic engineering can effectively be performed at the packet level without the assistance of ATM virtual circuits and TDM. Use of TDM and/or ATM for intermediate-level bandwidth management – especially where one or more OC-48c packet flows exist between routers – misapplies grooming devices for light-speed forwarding. Even worse, it increases latency and network restoration time.

Bandwidth provisioning across four-layer networks is complicated, time consuming and often requires extensive planning and manual intervention. Consequently, the four-layer model is ineffective as a scalable architecture for the next-generation Optical Internet.

The four-layer networking experience has led to the understanding that only two layers are necessary to achieve the desired attributes of the next-generation Optical Internet solution: the intelligent IP layer and the high-capacity multi-wavelength optical layer. However, these layers must be combined intelligently for the two-layer solution to be scalable and effective.

In one approach, called the *router-centric* architecture, IP routers are directly connected to each other via multi-wavelength fiber links, with the multi-wavelength optics terminated directly on the IP routers (see Figure 2). The multi-wavelength interface on the router is equivalent to a TDM channelized interface often used in today's network, but channelization is performed at the optical wavelength level.

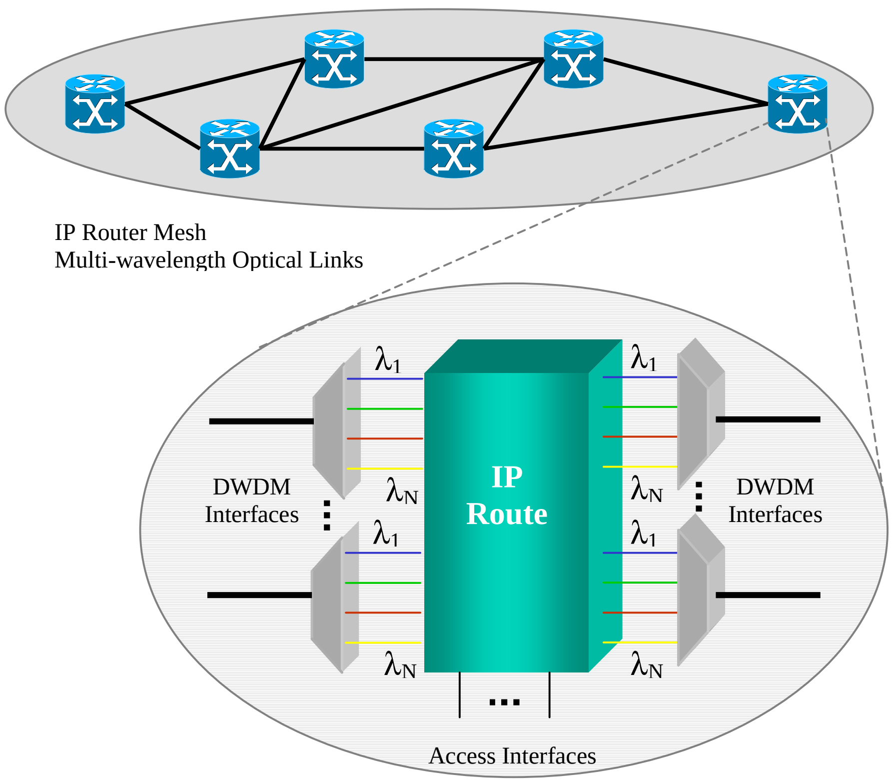

Figure 2: ***Router-centric Architecture***

With this architecture, the network topology is fixed and the network configurations are all static. There is no intelligent management of optical connectivity in this architecture. The optical layer only provides capacity and the IP layer only needs to maintain itself. There is minimal interaction between the two layers, with no blending of their most desirable attributes.

Although this architecture has the advantage of a simplified control structure, it does not provide the intelligent control of packet-over-optics and network scalability. For IP flow management, the processing speed must be tightly matched with the optical links to achieve effective control. Furthermore, this architecture tightly couples capacities of electronics and optics. This artificially limits scaling to the capacity of the electronics. As a result, the router-centric approach does not take full advantage of the optical capacity scaling.

In an alternative approach called the *multi-service optical networking* architecture, the IP and optical layers are distinct and maintained as completely separate networks (see Figure 3). IP routers are directly connected to optical network elements, such as an optical cross-connect (OXC), via an optical user-network interface (O-UNI). In this architecture, the optical cross-connects themselves are interconnected in a mesh configuration with multi-wavelength fiber links. By appropriately configuring the optical cross-connects, a given IP router interface can be connected to any other interface at any other router. As a result, the neighboring router for a given router interface is configurable within this architecture.

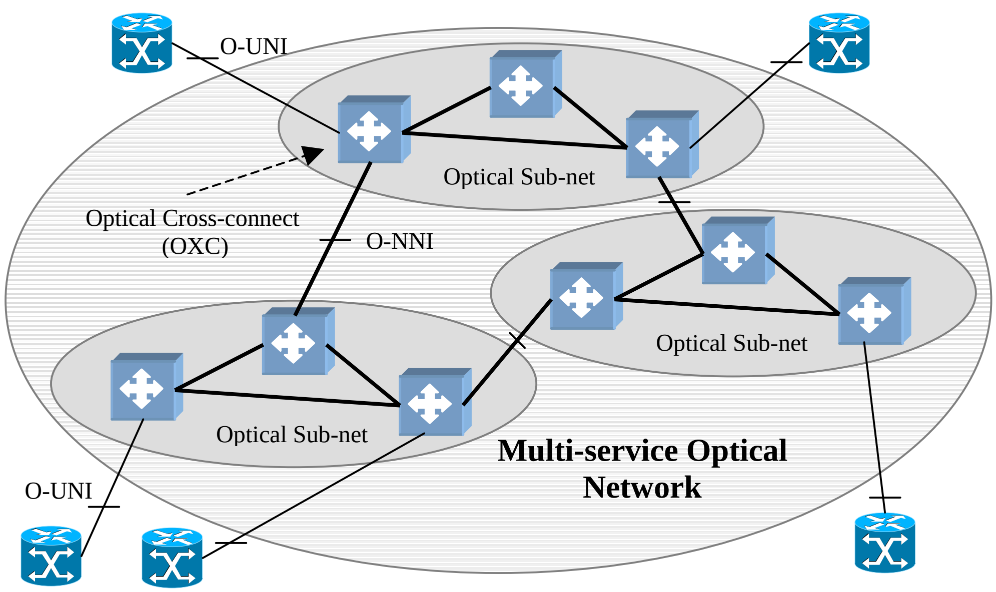

Figure 3: ***Multi-service Optical Networking Model***

The multi-service optical networking approach requires control messaging support or signaling across the O-UNI. This signaling is necessary to communicate, dynamically on-demand or in near real time, the needs of the IP layer to the optical network. This includes information about IP trunk provisioning, trunk bandwidth allocation and modification, route changes due to network failure, and other network activities or conditions. One type of signaling model suggested for the O-UNI is the *overlay model*, where the IP and optical layer devices relate to each other in a client-server relationship. Management and control of the two layers remain completely separate. Each layer therefore must provide its own control protocols and management system. There is no opportunity to share these resources among the separate networks. For the IP layer, control and management are standardized and well proven. For the multi-wavelength optical layer, however, the necessary addressing scheme and corresponding routing and signaling protocols are yet to be defined and standardized, let alone proven in the industry. Furthermore, to couple the IP and optical layer addresses, an address resolution protocol must be defined and built.

Additional issues with the overlay model are network restoration and traffic engineering. In the overlay model, operations in one layer are pursued independently from those in the other layer. Thus protection/restoration and traffic engineering solutions developed for IP networks or optical networks are applied directly to their respective layer with little or no inter-layer coordination. This separation makes it nearly impossible to optimize the IP/optical network with respect to network resource utilization, performance and recovery time following network failures. Even worse, uncoordinated actions at the optical layer may lead to significant service outage at the IP layer.

Although each of these various approaches has its respective merits, they are all ultimately ill suited for the next-generation Optical Internet architecture. Recognizing the deficiencies of the router centric and multi-service optical networking architecture approaches, Village Networks' *Optical Flow Networking* combines IP routing intelligence with high-capacity, multi-wavelength switched optics thereby enabling a truly intelligent, reliable and scalable networking solution for the next-generation Optical Internet.

Optical Flow Networking Defined

Optical Flow Networking fundamentally utilizes IP as the basic networking technology and multi-wavelength optics as the transport mechanism in a highly integrated, single networking node called an Optical Packet Node (OPN). In the OFN approach, the IP and optical layers are effectively collapsed into a single layer that combines the intelligence of IP with the scalable capacity of configurable, multi-wavelength optics (see Figure 4).

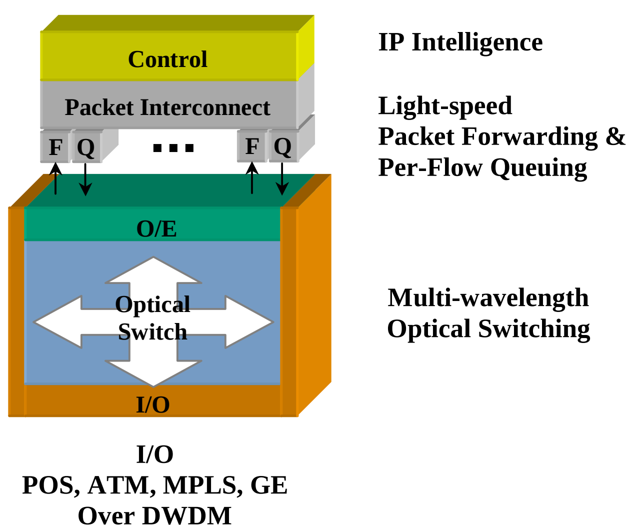

Figure 4: *OFN Integrated IP-Optical Networking Device*

The packet processing components in the OFN networking device provide control and manipulation of traffic at the granularity of individual IP flows. These components are designed to process data electronically at the per-packet level and at speeds matched to current and next-generation optical rates (e.g., 10 Gbps OC-192). The packet components provide light-speed operation of packet forwarding, per-flow queuing, and packet-over-lightpath adaptation/de-adaptation for enabling dynamic, QoS-enabled bandwidth management.

The intelligence for network control and management is provided by IP-based specifications, with optical extensions where needed, such as those defined in the IETF's MPLS and MPλS. This includes networking functions such as addressing, routing, admission control, topology discovery, neighbor discovery, QoS, traffic engineering and network restoration.

The optical processing components of the OFN networking device provide multi-wavelength transmission and switching, with the wavelengths per fiber density, transmission link distance and switching capacity scalable for metropolitan, regional and core-edge networks. Driven by the intelligence of the IP components, the optical components enable dynamic creation of multi-wavelength lightpaths, rapid rearrangement and adaptation of lightpath configurations, wavelength translation for flexible lightpath networking and fast restoration.

To build and scale new optical IP networks, OFN devices are distributed throughout a metropolitan, regional or wide area network and interconnected directly by one or more dark-fiber pairs or through an all-optical long-haul core (see Figure 5). The fiber topology may be either ring or mesh, dependent on the service providers' fiber plant requirements. Integration of IP and multi-wavelength optical processing and control in the OFN device lets service providers eliminate their intermediate SONET/SDH and ATM devices. The resulting OFN architecture is simple and highly efficient.

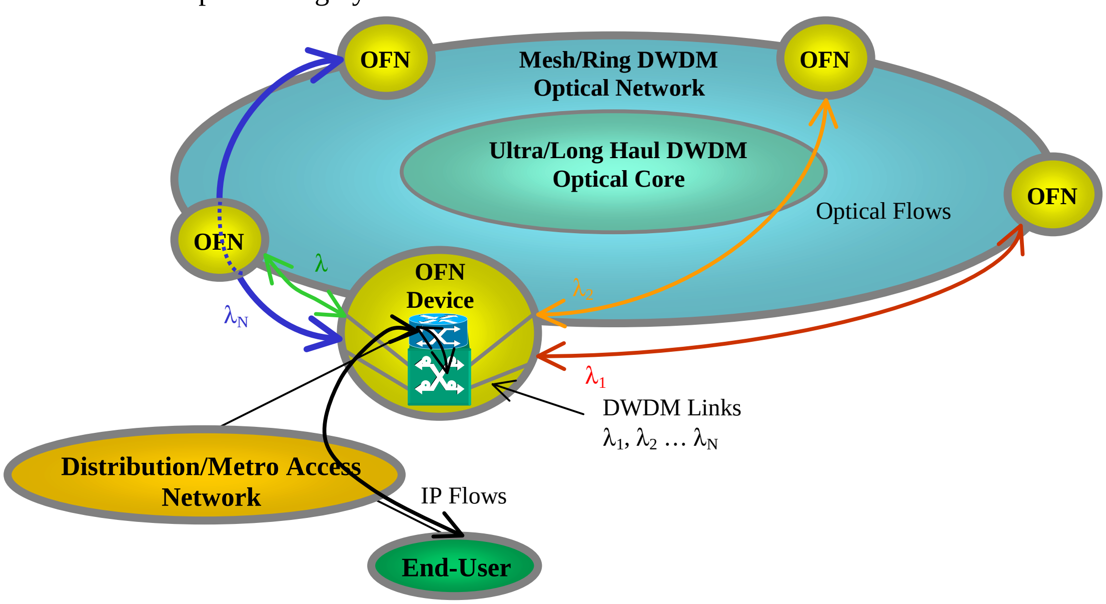

Figure 5: ***Optical Flow Networking Architecture***

At ingress from FR, Ethernet, ATM or POS-based aggregation or distribution networks, the OFN device creates QoS-differentiated IP flows and routes them onto optical IP tunnels, creating *optical flows* at OC-48c/192c rates. The optical IP tunnels are λ multi-hop lightpaths that are created and controlled using IP intelligence distributed among the OFN devices.

The OFN devices are capable of routing IP and switching wavelengths, enabling single-hop or multi-hop add/drop optical flow types. Driven by IP intelligence, this capability enables rapid optical flow creation, traffic engineering, and restoration in response to IP traffic demands and network states. As IP traffic increases or changes, existing lightpaths may be reconfigured or additional lightpaths created using the appropriate OFN devices. In the instance of a fiber cut, OFN devices detect and isolate the fault and redirect optical flows onto alternate lightpaths in sub-50 millisecond time (i.e. the SONET/SDH protection switch benchmark) to minimize service disruption.

In summary, the OFN solution is an integrated IP and multi-wavelength optical layer approach. The strengths of each layer are leveraged in a common, single networking device:

- The IP layer provides intelligence for network control and management
  - Addressing
  - Routing
  - Topology Discovery
  - Neighbor Discovery
  - QoS
  - Traffic Engineering
  - Restoration

- The Optical layer provides
  - Capacity
  - Dynamic connectivity via switched lightpaths
  - Physical transmission

The Optical Flow Networking architecture enables packet/optical resource scaling and distribution that enables service providers to respond to Internet traffic demands and growth flexibly and rapidly. Furthermore, the OFN solution provides the optical-scale bandwidth intelligence capabilities that enable service providers to offer and effectively manage QoS-differentiated IP-base services.

Optical Flow Networking Applied

Village Networks' Optical Flow Networking technology and architecture provides a scalable family of next-generation optical IP products. OFN delivers enhanced IP connectivity and application QoS services in access, metro/regional and core-edge networks. Supported applications include:

- Intelligent IP/λ bandwidth management
- Premium/tiered IP services with guaranteed performance
- Virtual private networking (VPNs) and virtual/transparent LAN services
- Gigabit Ethernet and IP/λ services
- Private Line Services via circuit emulation

- SAN internetworking
- Voice-over-IP networking

The OFN solution is a complete, seamless hardware, software and services platform that can be rapidly deployed in service provider networks. This solution complements the build-outs of long-haul/ultra long-haul optical core capacity, next-generation metro/regional access, IP data centers for content/Web hosting, applications and storage services, and service management and network operations centers.

Chassis-based OFN systems may be deployed in the service provider's Central Office or Point-of-Presence (POP). OFN supports a full range of interworking and interface standards, including BGP, IGP and EGP routing, MPLS, GMPLS, SONET/SDH, ATM, Gigabit Ethernet and VLAN.

To enable the service provider to take full advantage of the OFN solution, Village Networks has developed innovative software features that provide "point and click" dynamic IP/λ bandwidth provisioning, IP service protection and restoration, auto-inventory discovery and other automated functions. This software runs on an OFN management server that supports a full range of features needed to integrate effectively with OSSs and NOC workflow processes. XML, CORBA, Java, SNMP and CLI are some of the important APIs and interfaces supplied.

In short, OFN delivers unbreakable optical IP flows that enable service providers to offer premium IP services with unmatched reliability levels. Its instant packet-beam creation lets service providers customize IP and optical bandwidth cost-effectively to suit individual customer needs. Best of all, OFN's radical simplicity makes for easier network management and significantly reduces the total cost of ownership.

Optical Flow Networking Benefits

Optical Flow Networking solves the service providers' problem of speed, scalability and control by providing intelligently managed, highly reliable, IP-based optical networking. The OFN solution enables SPs to have complete visibility and control across both the optical and IP domains. Without this capability, they cannot provide differentiated services with appropriate service levels over a single optical pipe. Furthermore, OFN is the first approach on the market that offers:

- Flexible, dynamic packet-over-lightpath bandwidth creation and management for maximizing network resource utilization.
- QoS-based packet forwarding and control at optical rates for achieving optimal network performance.
- Topology-independent (ring or mesh) packet-over-lightpath service restoration that is fast and efficient for insuring reliable, fail-safe networking.
- Efficient, flexible & scalable architecture that optimally matches optical capacity with lightspeed electronic processing.
- Simplified network planning and management of IP over multi-wavelength optical networks.

- Substantially reduced network equipment and operational costs – up to 40% savings in capital expense and over 65% savings in operational costs[2] (see Figure 6).

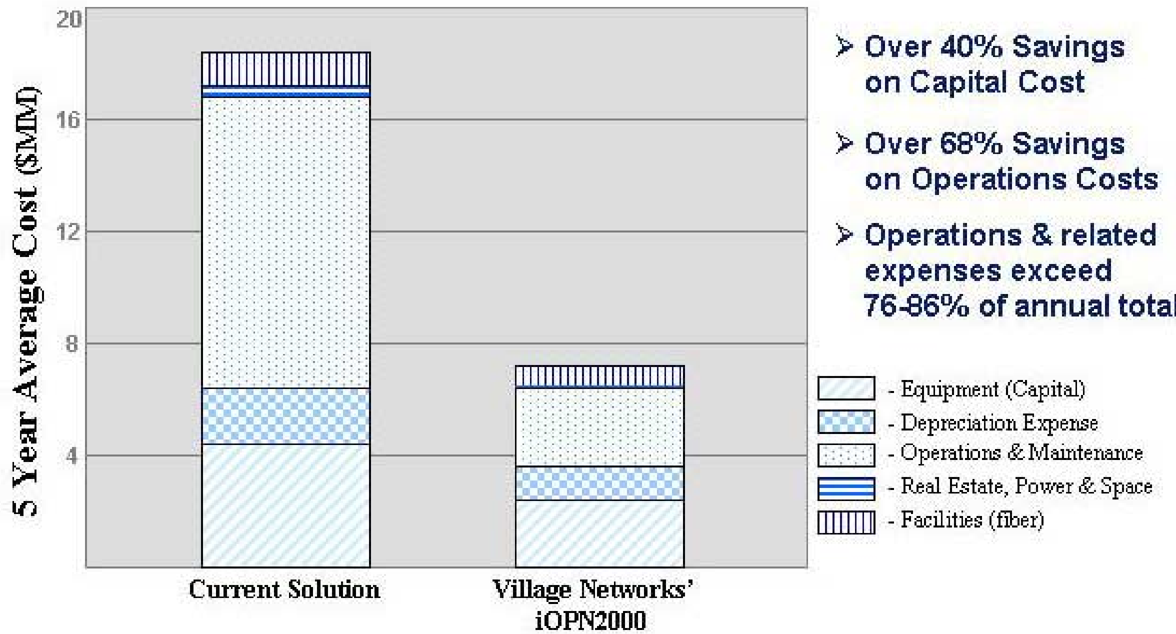

Figure 6: *Optical Flow Networking Architecture*

Optical Flow Networking: Solution for Next-Generation Optical Internet

Village Networks has developed a powerful, yet simple solution to service providers' next-generation Optical Internet needs with its revolutionary *Optical Flow Networking*[SM] architecture. OFN uses breakthrough technology that tightly integrates light-speed packet processing with switched, multi-wavelength optical networking in a single device. The OFN architecture thereby achieves new levels of "intelligent" network level bandwidth control, performance and reliability not possible with multiple, discrete devices. This solution delivers for service providers highly reliable, QoS-differentiated, IP over multi-wavelength optical networking. Village Networks' OFN solution addresses the immediate service provider challenge of scaling the network for rapid, reliable, and intelligent bandwidth delivery for IP over multi-wavelength optics, and lays the foundation for the next-generation Optical Internet.

[2] *Comparative Cost of Delivering Services*, Probe Research, Inc., January 8, 2001

About Village Networks

Village Networks (www.villagenetworks.com) is the industry leader in integrated IP-over-optics solutions. The company's iOPN Optical Packet Node product family integrates light-speed packet processing with high-capacity optical switching, enabling Optical Flow Networking. This breakthrough networking solution provides enhanced differentiated service capabilities in a dramatically simplified network architecture that significantly reduces total cost of ownership. Founded in 1998, Village Networks is headquartered in Eatontown, NJ.