

Evaluation of Cisco Wide Area Application Services (WAAS)



Introduction

Choosing the best WAN optimization solution for branch-office consolidation and acceleration can be challenging because of the wide range of solutions that are currently available from more than a dozen vendors. In the course of conducting a broad market survey of enterprise requirements for WAN optimization and application acceleration, Ashton, Metzler & Associates (AM&A) has developed a set of evaluation criteria that can assist IT organizations in the selection of WAN optimization solutions. For example, the criteria could be used as the basis for an initial screening of vendor solutions to compile a short list of vendors whose solutions would be examined more carefully before a purchase decision is made. Another possible use of the criteria is as an aid in developing a more detailed RFP to give to vendors on the short list.

The remainder of this document provides a brief discussion of the selection criteria plus an evaluation of how the Cisco® WAN optimization solution based on Cisco Wide Area Application Services (WAAS) Software Version 4.0 meets these criteria. Therefore, this document provides an example of the sort of preliminary analysis that would typically be done by IT organizations to narrow the field of vendors to a short list of potential solutions.

The evaluation of the Cisco solution is based primarily on an examination of various documents posted at the Cisco Website, including the Cisco WAAS Software Version 4.0.1 configuration guide.

Evaluation Criteria

Table 1 lists the recommended criteria for evaluating WAN optimization solutions. Note that this list is intended as a fairly complete compilation of all possible criteria, so a given organization might apply only a subset of these criteria for a given purchase decision. In addition, individual organizations can be expected to ascribe different weights to each of the criteria because of differences in WAN architecture, branch-office network design, and application mix. As shown in the table, assigning weights to the criteria and relative scores for each solution provides a simple methodology for comparing competing solutions.

IT organizations can use many techniques to complete Table 1 and then use the contents of Table 1 to compare alternative solutions. For example, the weights can range from 10 to 50 points, with 10 points meaning not important, 30 points meaning average importance, and 50 points meaning critically important. The score for each criterion can range from 1 to 5, with 1 meaning fails to meet minimum needs, 3 meaning acceptable, and 5 meaning significantly exceeds requirements.

For the sake of example, consider solution A. For this solution, the weighted score for each criterion ($WiAi$) is found by multiplying the weight (Wi) of each criterion by the score of each criterion (Ai). The weighted scores for all the criteria are then summed ($\sum WiAi$) to get the total score for the solution. This process can then be repeated for additional solutions, and the total scores of the solutions can be compared.

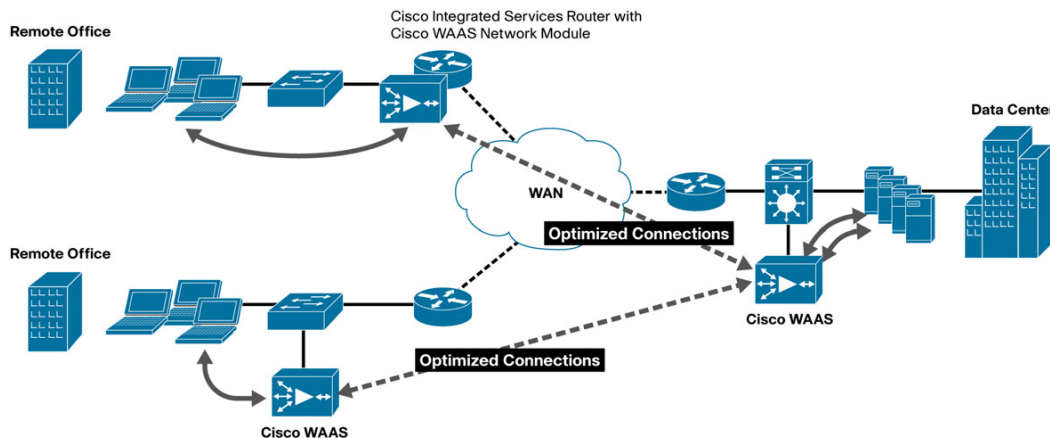
Table 1 Criterion for WAN Optimization Solutions

Criterion	Weight Wi	Score for Solution A Ai	Score for Solution B Bi
Performance			
Transparency			
Solution Architecture			
Open Systems Interconnection (OSI) Layer			
Application Monitoring Capability			
Scalability			
Cost Effectiveness			
Application Subclassification			
Module or Application Optimization			
Disk- or RAM-Based Compression			
Protocol Support			
Security			
Ease of Deployment and Management			
Change Management			
Support for Meshed Traffic			
Support for Real-Time Traffic			
Total Score		$\sum WiAi$	$\sum WiBi$

Cisco WAAS

As shown in Figure 1, the Cisco solution consists of Cisco WAAS Software running on Cisco Wide Area Application Engine (WAE) Appliances at both branch and central sites. These appliances can be deployed either as standalone devices or as modules in a Cisco Integrated Services Router.

Figure 1 Cisco WAAS



Evaluating Cisco WAAS

This section evaluates Cisco WAAS based on the criteria in Table 1.

Performance

Description of the Criteria:

Third-party tests of a solution can be helpful. It is critical, however, that you quantify the kind of performance gains that the solution will provide in the particular environment where it will be installed. For example, if the IT organization already has consolidated, or is in the process of consolidating, branch-office servers in centralized data centers, then testing must show how well the WAN optimization solution supports Common Internet File System (CIFS).

As part of this quantification, you must also determine whether performance degrades as additional functions within the solution are activated or as the solution is deployed more broadly across the organization.

Evaluation of Cisco:

Cisco sponsored a third-party performance evaluation by Miercom. That evaluation included testing of HTTP and FTP acceleration, CIFS, Microsoft Office remote file operations, and Microsoft Exchange downloads. The test results show that under favorable conditions (large WAN latency and highly compressible content), the Cisco WAAS 4.0 solution provides impressive degrees of acceleration. For example, the Miercom tests of file transfers using HTTP and FTP showed compression rates of 98 percent or higher.

When comparing Cisco WAAS to other solutions, Miercom concluded that Cisco WAAS Software

demonstrated performance parity with these other products, and that in some crucial metrics it provided superior compression, speed, and throughput. Miercom also concluded that unlike some of the other products on the market, Cisco WAAS does not degrade under load.

Transparency

As mentioned, for many IT organizations the first rule of networking is that you should not do anything that causes the network to break. For example, it should be possible to implement a WAN optimization solution and not break existing functionality such as security, QoS or routing. It should also be possible to implement a WAN optimization solution and still be able to use the existing management and monitoring tools. Given that WAAS does not change the packet headers and exports NetFlow data, it provides a high degree of transparency. That transparency has an impact on TCO as well as the following factor.

When testing products such as WAN optimization solutions, IT organizations typically test performance. AM&A recommends that IT organizations also test the transparency of these solutions.

Evaluation of Cisco:

With Cisco WAAS 4.0, all packet header information is preserved. As a result, Cisco WAAS integrates easily with the existing infrastructure, including clients, servers, storage, and networking devices. Cisco WAAS is also transparent in the sense that accelerator appliances can use auto-discovery to determine whether a peer accelerator is available at the other end of the link. After auto-discovery, a pair of accelerators can auto-negotiate an acceleration policy to be applied to the application flow. If a peer accelerator is not discovered, the application flow passes through unchanged.

Cisco is one of only a few vendors in this market that preserves the header information. That does not mean that it is impossible for Cisco WAAS to break something. It also does not mean that a solution that changes the header information will always break something. What it does mean is that vendors that change header information will have to implement a workaround to be as transparent as a solution that does not modify header information.

Solution Architecture

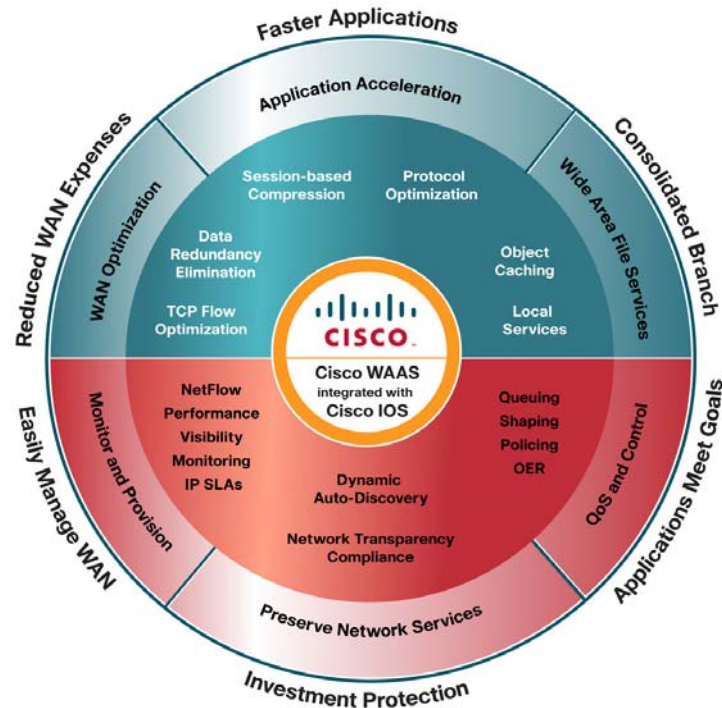
Description of the Criteria:

If the organization intends the solution to be able to support additional optimization functions over time, you must determine whether the hardware and software architecture can support new functions without an unacceptable loss of performance.

Evaluation of Cisco:

Cisco WAAS adheres to a layered architecture (Figure 2) that facilitates the addition of enhanced functions and maximizes the independence between functions. Whether there is enough processing capacity to adequately service a large number of sessions with multiple simultaneous functions depends primarily on the scalability of the Cisco WAE hardware platform that is chosen. As a result of its testing, Miercom concluded that Cisco WAAS shows fairness of connection throughput and performance consistency across concurrent users and multiple workloads.

Figure 2 Cisco WAAS Architecture



OSI Layer

Description of the Criteria:

Organizations can apply many of these optimization techniques at various layers of the OSI model. They can apply compression, for example, at the transport layer. The advantage of applying compression at this layer is that it supports all transport protocols and all applications. The disadvantage is that it cannot directly address any problems that occur higher in the stack.

Alternatively, having an understanding of the semantics of the application means that compression can also be applied to the application: for example, to SAP or Oracle traffic. Applying compression or other techniques such as request prediction in this manner can potentially be more effective.

Evaluation of Cisco:

Cisco WAAS operates at both the transport and the application layers. At the transport layer, Cisco WAAS applies TCP transport flow optimization (TFO), Persistent Lempel-Ziv (LZ) Compression, and Cisco WAAS Data Redundancy Elimination (DRE) to minimize latency and bandwidth consumption. At the application layer, Cisco WAAS employs application proxies and caches to reduce latency and minimize data flows over the WAN.

However, the performance effect of optimization techniques applied at specific layers of the OSI model is less important than how the WAN optimization solution actually performs in the environment in which it will be deployed. Nevertheless, Cisco support for implementation of optimization techniques at multiple layers of the OSI model gives IT organizations greater flexibility to implement optimization techniques in whatever manner makes the most sense, which should result in enhanced performance.

Capability to Perform Application Monitoring

Many network performance tools, such as NetQoS ReporterAnalyzer and SuperAgent, rely on network-based traffic statistics gathered from network infrastructure elements at specific points in the network to perform their reporting. WAN optimization is a disruptive network technology that optimizes applications across the WAN. By design, all WAN optimization devices apply various optimization techniques on the application packets and hence affect these network-based traffic statistics to varying degrees. One of the important factors that determines the degree of these effects is the amount of the original TCP/IP header information retained in the optimized packets.

On the other hand, most end-to-end application response-time monitoring tools rely on performing their analysis on the TCP-header information obtained from the network packets. By design, all WAN optimization solutions intercept and terminate TCP connections from the client to the server to optimize the payload and its subsequent transport. This changes the original TCP-header information from the client to the server. To be more specific, what typically is a single TCP connection between a client in the remote branch and a server in the Data Center is broken into three TCP connections when a pair of WAN Optimization devices is introduced to optimize the connection. This occurs across all WAN Optimization vendors. WAN optimization is thus a disruptive technology that presents a problem to the thousands of customers who have invested in application performance monitoring tools.

Evaluation of Cisco:

Cisco WAAS is a network-transparent solution which retains the original TCP header information between a client and server. Cisco and NetQoS have collaborated to develop a software interface integrated on all WAAS devices that permits SuperAgent, the end-to-end performance monitoring module of the NetQoS Performance Center, to capture the TCP header information from the WAAS devices and calculate end-to-end response times between the client and server over an optimized link. SuperAgent will enable users to view reports that quantify the latency improvements delivered by WAAS.

NetQoS ReporterAnalyzer, by virtue of its reliance on Cisco IOS® Netflow data as an input, works seamlessly (with no additional configuration) when WAAS is introduced in the network. The transparent integration of WAAS with ReporterAnalyzer allows organizations to maintain their current visibility into WAN link utilization and throughput.

Through the above transparent integration, only Cisco WAAS and the NetQoS Performance Center, with its SuperAgent and ReporterAnalyzer product modules, provide an integrated solution for complete and accurate visibility into end-to-end response time and traffic flow data (via NetFlow) even after optimization occurs. This visibility allows enterprises to quantify the application acceleration and WAN optimization improvements offered by Cisco WAAS by reporting pre- and post-optimized traffic accurately.

Scalability

Description of the Criteria:

One aspect of scalability is the size of the WAN link that can be terminated on the appliance. More important is how much throughput the appliance can actually support with the relevant and desired optimization functions turned on. Other aspects of scalability include how many simultaneous TCP connections the appliance can support and how many branches or users a vendor's complete solution can support.

Downward scalability is also important. Downward scalability refers to the capability of the vendor to offer cost-effective products for small branches or even individual laptops.

Evaluation of Cisco:

Cisco WAAS Software runs on a family of five models of Cisco WAE Appliances, including single-processor and dual-core-processor models for the branch office that scale to 2X 300 GB of disk storage and 2 to 4 GB of RAM and a dual-processor Cisco WAE Appliance for the central site or large branch office that scales to 3 terabytes (TB) of storage and 24 GB of RAM. Network interfaces for all these devices are two 10/100/1000BASE-T ports.

The Cisco WAE can be installed in the network in two ways. It can be installed offline with Web Cache Communication Protocol Version 2 (WCCPv2) or Cisco Policy-Based Routing (PBR) to redirect TCP traffic to the “one-armed” appliance. Alternately, it can be installed inline, with the Cisco WAE device deployed between the switch and the WAN router so that all packets leaving the remote office traverse the Cisco WAE.

At the branch office, the inline configuration can be scaled up by installing multiple Cisco WAE devices in series. This form of daisy-chain clustering provides active-active redundancy because the Cisco WAE has a fail-to-wire feature that bypasses the device in the event of failure. At smaller branch offices, the solution can be scaled down by using Cisco WAE modules installed in Cisco Integrated Services Routers. Larger central sites can scale up using load-balanced arrays of Cisco WAE Appliances with redirection controlled by WCCP.

As previously noted, Miercom concluded that Cisco WAAS shows fairness of connection throughput and performance consistency across concurrent users and multiple workloads, and that Cisco WAAS optimization does not degrade under load.

Cost Effectiveness

Description of the Criteria:

Cost effectiveness is related to scalability. In particular, IT organizations need to understand what the initial solution costs. They also need to understand how the cost of the solution changes as the scope and scale of the deployment increases.

Evaluation of Cisco:

Retail pricing of the Cisco solution is not publicly available information. The cost effectiveness, however, of the Cisco WAAS solution is enhanced by the position of Cisco in the enterprise networking market. Cisco is in a unique position to help ensure that its solutions integrate with the existing networking infrastructure, including routers, load balancers, and content distribution appliances, and also Cisco Application Control Engine (ACE), which is used by IT organizations to maximize the performance of Web-based applications and to maximize the availability and performance of servers.

The more seamlessly a WAN optimization solution integrates with the existing infrastructure, the more positive the effect on the overall total cost of ownership (TCO). Thus, AM&A recommends that IT organizations test integration when testing other features of a WAN optimization solution such as performance and transparency.

Application Sub-classification

Description of the Criteria:

An application such as one from Citrix or SAP consists of multiple modules with varying characteristics. Some branch-office optimization solutions can classify traffic at the individual module level, whereas others can classify traffic at only the application level.

Evaluation of Cisco:

For QoS purposes, Network-Based Application Recognition (NBAR) in Cisco routers can be used to identify and classify traffic for the various modules within enterprise applications. Cisco WAAS uses static Layer 4 port numbers and universally unique identifiers (UUIDs) of applications that use dynamic port numbers to classify traffic for acceleration. Therefore, any application module that can be distinguished in this way can be assigned a custom acceleration policy.

Module or Application Optimization

Description of the Criteria:

Some branch-office optimization solutions handle each module of an application in the same fashion. Other solutions handle modules based on both the importance and characteristics of that module. For example, some solutions apply the same optimization techniques to all SAP traffic, and other solutions would apply different techniques to the individual SAP modules based on factors such as their business importance and latency sensitivity.

Evaluation of Cisco:

Cisco WAAS supports 500 application classifiers with predefined default policies for more than 150 application classifiers based on Layer 4 port numbers. The Cisco WAAS default policy applies the full suite of packet-level optimizations (Persistent LZ Compression, TFO, and Cisco WAAS DRE) to all enterprise application traffic, including Citrix, Oracle, and SAP traffic. Cisco WAAS also provides the flexibility to define custom policies for specific applications. If the application module can be classified by Layer 4 port number or UUID, it can be assigned a custom policy independent of the other modules of the same application.

Disk- or RAM-Based Compression

Description of the Criteria:

Advanced compression solutions can be either disk or RAM based. Disk-based systems typically can store up to 1000 times the volume of patterns in their dictionaries as RAM-based systems, and those dictionaries can persist across power failures. However, access to the data is slower than it is in typical RAM-based implementations, although the performance gains of a disk-based system are likely to more than compensate for this delay. Although disks are more cost effective than RAM-based solutions on a per-byte basis, because of the size of these systems, they do add to the overall cost of a solution and introduce additional points of failure. Standard techniques such as RAID can mitigate the risk associated with these points of failure.

Evaluation of Cisco:

Cisco WAAS DRE and Persistent LZ Compression currently focus on TCP traffic where large disk-based data dictionaries provide the maximum compression ratios. Cisco WAAS session-based Adaptive LZ Compression is RAM-based and minimizes the amount of bandwidth consumed per message within a session. RAM-based compression solutions are also applicable for real-time compression of User Datagram Protocol (UDP) packet streams such as those produced by video applications and voice over IP (VoIP). UDP applications are not currently supported by Cisco WAAS. Cisco WAE Appliances with two or more disks are configured with RAID1 mirroring pairs to protect against disk failures.

Protocol Support

Description of the Criteria:

Some solutions are specifically designed to support a given protocol (for example, UDP, TCP, HTTP, Microsoft Print Services, CIFS, or Messaging Application Programming Interface [MAPI]), and other solutions support that protocol generically. In either case, the critical concern is how much the solution can improve the performance of that protocol in the type of environment in which the solution will be deployed.

You also need to determine whether the solution makes any modifications to the protocol that could cause unwanted side effects.

Evaluation of Cisco:

The Cisco WAAS TCP optimization features (TFO, Cisco WAAS DRE, and Persistent LZ Compression) provide optimizations for all applications that use TCP. In addition, Cisco WAAS supports some application-specific acceleration features:

- **Operation prediction and batching:** These features enable a Cisco WAAS device to transform a command sequence into a shorter sequence over the WAN to reduce roundtrips.
- **Intelligent message suppression:** Even though TFO optimizes traffic over a WAN, protocol messages between branch-office clients and remote servers can cause slow application response times. To resolve this problem, each Cisco WAAS device contains application proxies that can respond to messages locally so that the client does not have to wait for a response from the remote server. The application proxies use a variety of techniques, including caching, command batching, prediction, and resource prefetch, to increase the response times of remote applications.
- **Cisco WAFS Software caching:** This feature enables a Cisco WAAS device to reply to client requests using locally cached data instead of having to retrieve this data from remote file and application servers.

Currently, Cisco WAAS supports these types of application-specific functions for Microsoft CIFS and Microsoft Print Services.

However, to determine which protocol support matters and which vendor's implementation yields the greatest performance gains, the best approach is to test the solution in an environment similar to the one in which it will be deployed.

Security

Description of the Criteria:

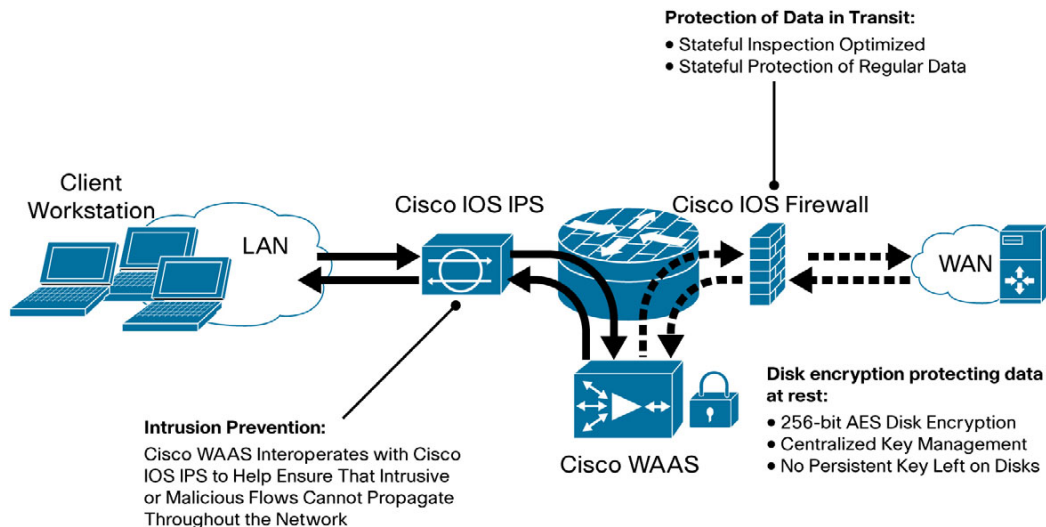
The solution must not break the current security environment: for example, it should not break firewall access control lists (ACLs) by hiding TCP header information. In addition, the solution itself must not create any additional security vulnerabilities.

Evaluation of Cisco:

Cisco WAAS preserves the native packet headers, allowing switch and router ACLs and stateless and stateful firewalls to function normally. Because the packet payload is compressed, the functions of any security devices (for example, Cisco IOS Intrusion Prevention System [IPS]) that perform deep packet inspection beyond the header in the payload will be affected. This limitation applies to most WAN optimization devices that use compression.

Cisco WAAS incorporates the following security and data protection capabilities, summarized in Figure 3.

Figure 3 Data Protection Capabilities of Cisco WAAS Solution



- **Disk encryption:** Encryption of all cached content on the remote Cisco WAE Appliance prevents unauthorized data access or theft. Federal Information Processing Standard (FIPS) 197–approved technology and Advanced Encryption Standard (AES) 256-bit encryption, the strongest commercially available encryption, is used. The automated central key manager simplifies key management, provides centralized failover capability for high availability, and supports backup and restoration of keys to offline vaults for disaster recovery purposes.
- **Security compliance:** Cisco WAAS combined with Cisco IOS Software provides stateful firewall inspection for accelerated traffic, network virus scanning using Cisco IOS IPS and encryption of data at rest, maintaining compliance with common industry-wide security standards. In addition, Cisco WAAS supports role-based access control (RBAC) to isolate users to specific capabilities and domains of management. Cisco states that Cisco WAAS is the only WAN optimization solution approved for evaluation in the Common Criteria Evaluation and Validation Scheme (CCEVS), or ISO 15408, and that it complies with Payment Card Industry (PCI) 1.1.
- **Stateful firewall protection:** Because Cisco WAAS supports stateful inspection of WAN-optimized traffic through certified interoperability between its firewalls and Cisco WAAS, IT organizations can receive equal protection for optimized and regular data through these capabilities:

- Full stateful protection for Cisco WAAS optimized traffic
- Full stateful operation for nonoptimized traffic
- No static open ports needed except for management and CIFS
- **Cisco IOS IPS interoperability:** Cisco IOS IPS provides virus scanning in the network while maintaining full interoperability with Cisco WAAS, thus allowing customers to perform WAN optimization while protecting their networks against viruses.
- **RBAC:** The Cisco WAAS Central Manager offers AAA integration with external authentication providers such as Microsoft Active Directory, RADIUS, and TACACS+. Customers can create profiles based on role, department, responsibility, and other parameters to help ensure secure access to Cisco WAAS.

Ease of Deployment and Management

Description of the Criteria:

In deploying a WAN optimization solution, appliances will likely need to be deployed in branch offices that do not have any IT staff. Thus, it is important that unskilled personnel can install the solution. In addition, the greater the number of appliances deployed, the more important it is that they are easy to configure and manage.

Evaluation of Cisco:

Cisco WAAS Central Manager is a Web-based central management tool that provides simplified configuration, provisioning, monitoring, fault management, logging, and reporting for up to 2500 Cisco WAE Appliances within a Cisco WAAS topology. Cisco WAAS requires no modifications to applications, clients, or servers in order to provide acceleration services.

A number of factors make Cisco WAAS relatively easy to deploy. For example, Cisco WAAS does not rely on tunnels. For this reason and the fact that most of the existing network equipment is from Cisco, the Cisco WAAS solution is less likely to break the existing network than are some other solutions. A solution that breaks the existing network cannot be considered easy to deploy and maintain.

In addition, Cisco WAAS supports auto-discovery whereby the solution determines whether a peer acceleration appliance exists in the packet flow between the source and the destination. If one does, an optimization policy is transparently negotiated and then applied. If one does not, the application flow is not changed. Auto-discovery is helpful in those situations in which a WAN optimization solution has been deployed in some sites but not others. This feature eliminates the need to have IT organizations implement an overlay network. A solution that requires creation of an overlay network is also not easy to deploy and maintain.

Change Management

Description of the Criteria:

Because most networks experience periodic changes such as the addition of new sites or new applications, the WAN optimization solution must be able to adapt to these changes easily, preferably automatically.

Evaluation of Cisco:

With auto-discovery of Cisco WAE Appliances and auto-negotiation of application policies, new sites and new applications can be added to the network with a high degree of automation. In addition, the Cisco WAAS Central Manager automates the download of new configuration files to device groups of Cisco WAE Appliances that share a common configuration.

Support for Meshed Traffic

Description of the Criteria:

A number of factors are causing a shift in the flow of WAN traffic away from a simple hub-and-spoke pattern to more of a meshed flow. A company making this transition should be sure that the WAN optimization solution that it deploys can support meshed traffic flows and a range of features such as asymmetric routing.

Evaluation of Cisco:

Because of its transparency, the Cisco WAAS solution operates completely independent of the WAN architecture, including partially or fully meshed architectures.

Support for Real-Time Traffic

Description of the Criteria:

Many companies have deployed real-time applications. For these companies, the WAN optimization solution must be able to support real-time traffic.

Some real time traffic, such as VoIP and live video, cannot be accelerated because it is flowing in real time and is already highly compressed. Header compression may be helpful for VoIP traffic, and most real-time traffic benefits from QoS.

Evaluation of Cisco:

In the Cisco approach, header compression and QoS functions are provided by Cisco routers in the branch-office and central-site routers. Cisco WAAS does not modify the traffic generated by real-time applications running over UDP, such as voice and video. However, for video, Cisco offers Cisco Application and Content Networking System (ACNS) Software for Cisco WAE Appliances that optimizes video distribution. For VoIP, Cisco WAAS is fully compatible with the required end-to-end QoS function while also maximizing the bandwidth available for voice traffic by compressing and optimizing TCP data traffic sharing the same WAN circuits.

The question of which functions should be performed in a router and which should be performed in a separate appliance is an architectural challenge that is beyond the scope of this document. However, whatever function is invoked in the router needs to be harmonized with whatever function is invoked in an appliance. For example, if QoS is set in the router, the appliance should not do anything to interfere with it.

Summary

The criteria listed in Table 1 were applied to the Cisco WAN optimization solution. Although no attempt was made to assign a grade to the solution, the analysis did point out that Cisco WAAS has a number of strengths:

- **Transparency:** For many IT organizations the first rule of networking is that you should not do anything that causes the network to break. For example, you should be able to implement a WAN optimization solution and not break existing functions such as security, QoS, or routing. You should also be able to implement a WAN optimization solution and still use the existing management and monitoring tools. Because Cisco WAAS does not change the packet headers, it provides a high degree of transparency. That transparency has a positive effect on TCO as well as on ease of deployment and management.
- **Ease of deployment and management:** Because it does not modify packet headers, Cisco WAAS is less likely to break some aspect of the network than are some other solutions. As a result, Cisco WAAS is easier to deploy and manage than solutions that do not offer this benefit. In addition, Cisco WAAS supports auto-discovery, whereby the solution determines whether a peer acceleration appliance exists in the packet flow between the source and the destination. This feature makes deployment easier by eliminating the need to have IT organizations implement an overlay network.
- **Integration:** Although integration is not one of the criteria listed in Table 1, it affects several of the criteria in the table. Because of the position of Cisco in the enterprise networking marketplace, the environment in which a WAN optimization solution is deployed likely will be a Cisco environment. Cisco is in the best position to help ensure that its WAN optimization solution does not negatively affect this environment.
- **Performance:** Miercom made the following comments about Cisco WAAS:
 - Under favorable conditions (large WAN latency and highly compressible content), the Cisco WAAS 4.0 solution can provide impressive degrees of acceleration.
 - The software demonstrated performance parity with the other products, and in some crucial metrics it provided superior compression, speed, and throughput.
 - Unlike some of the other products on the market, Cisco WAAS does not degrade under load.