Wireless Broadband anytime & anywhere.

Improving Coverage and Quality in Video Surveillance Applications

August 2008

Azalea NETWORKS

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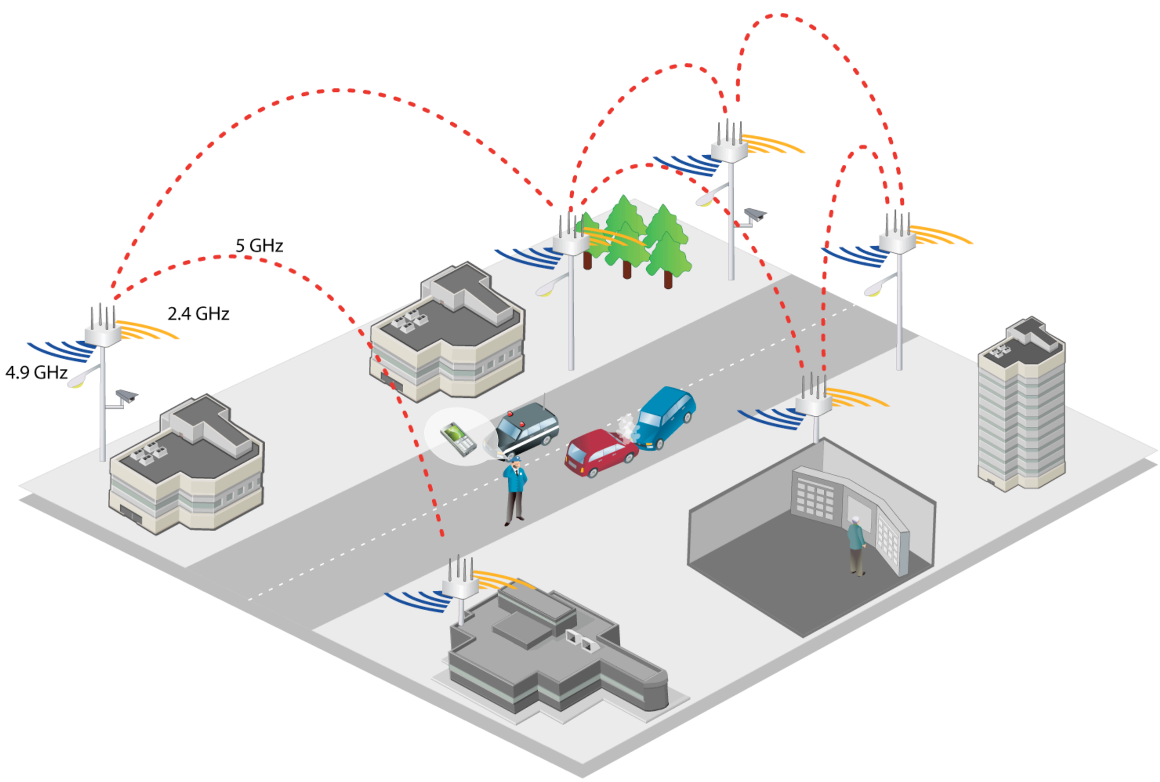
Executive Summary

Video surveillance traces its roots to the 1960's when closed-circuit television was first used to monitor and record activities at remote locations. Technology has advanced substantially in nearly half a century since then, making video surveillance more versatile and affordable than ever before. With so many advances in digital cameras, video compression, wireless networks and other areas, it is now feasible and cost-effective to make video surveillance more widespread, and therefore, more effective.

Indeed, these advances have motivated public agencies and private corporations alike to consider implementing video surveillance on an unprecedented scale. Law enforcement agencies, for example, have found surveillance to be a particularly powerful tool for deterring crime, responding to incidents faster based on constant monitoring, and performing the forensic analysis required to identify and prosecute perpetrators. And organizations with infrastructures dispersed over broad areas are now realizing similar results for public transportation, university and corporate campuses, business parks, and various industries from construction and logistics to mining and oil and gas.



Video surveillance applications have benefited substantially from advances in technology, including the expanded coverage, seamless roaming and superior video quality afforded by the network intelligence in Azalea's wireless broadband infrastructure.

While the state-of-the-art has advanced considerably from the early days of video surveillance, some barriers remain to deploying cameras on a large scale over broad geographies. Limitations inherent in wireless communications render some solutions incapable of supporting real-time applications like voice and video. And most of the solutions that do claim to support video surveillance often do so with unacceptably poor video quality. Supporting hundreds or thousands of cameras over large areas with good quality is certainly possible and affordable today, but it is by no means a trivial endeavor.

This white paper, intended for IT professionals but suitable for business decision-makers, is organized into four remaining sections followed by a brief conclusion. The first section on Advances in Video Surveillance highlights some pertinent history on advances in various areas, particularly in digital video and wireless networking technologies. The second section on Remaining Impairments to Coverage and Quality explores some of the limitations inherent in wireless networking, and how these affect video surveillance applications. The third section on Wireless Routing Enables Ubiquitous Coverage explains how Azalea was able to integrate routing at the network layer with related enhancements at both the data link and physical layers to achieve industry-leading network intelligence that overcomes these inherent limitations. The fourth section on Traffic Shaping Delivers "High-definition" Video Quality describes additional and unique capabilities that enhance video quality. Additional information on these and other topics is available on the Web at www.azaleanet.com.

Advances in Video Surveillance

The many technologies involved in video surveillance applications have advanced significantly since the 1960's when analog closed-circuit television (CCTV) was considered the state-of-the-art. CCTV employs bulky and costly coaxial cable, which must be run directly from the cameras to the monitoring and recording equipment. Special converters enabled the use of less expensive unshielded twisted pair (UTP) wiring, but the point-to-point nature of CCTV remained the same, and a major impediment to more ubiquitous deployments.

The most significant breakthrough advance for video surveillance came with the advent of the charge-coupled device (CCD) that digitizes video images. CCD technology is so affordable that it is now built into many mobile phones as a digital camera and laptop computers as a Webcam. Although CCTV equipment is still available, virtually all new video surveillance applications now employ digital cameras, monitors and recorders.

The digitization of still pictures and full-motion video cleared the way for a variety of other advances on numerous fronts. Digital communications enables the use of more flexible network options, from circuit-based time-division multiplexing (TDM) to packet-based Ethernet and IP. Indeed, most modern digital cameras have a built-in Ethernet interface, and many now offer Wi-Fi capability. These cameras are also far more intelligent and versatile, possessing advanced features like remote-control pan/tilt/zoom (PTZ) that allow for broader and better coverage from each camera.

Another front that has witnessed considerable advancement involves compression technology. Basic uncompressed, low resolution video transmitted at 15 frames per second with a small frame size of just 320x240 pixels consumes about 1 Mbps of bandwidth. Because most users want higher resolution, today's "megapixel" cameras normally employ some form of compression, such as one of the versions of MPEG from the Motion Picture Experts Group. These cameras often generate video streams requiring some 3 Mbps of bandwidth each, and a large-scale video surveillance application may require hundreds or even thousands of cameras.

The final barrier to ubiquitous deployment of video surveillance cameras was eliminated with the advent of broadband wireless networking. With wireless networks, there are no longer the long lead times and high initial costs of trenching to lay UTP or fiber optic cabling (as much as $250,000 per mile in some locations), or the high ongoing monthly fees for leased line, digital subscriber line (DSL) or metropolitan Ethernet services available in the Public Switched Telephone Network (PSTN).

The world of wireless communications itself presents many options. While some solutions utilize laser beams, or free space optics, most utilize radio frequency (RF) communications. RF-based solutions range from wireless mesh to point-to-point and point-to-multipoint systems. Wireless networks can be deployed by any organization in the unlicensed spectrum (2.4 GHz and 5 GHz), and U.S. government agencies can now utilize spectrum licensed by the Federal Communications Commission (FCC) exclusively for public safety needs (4.9 GHz).

These advancements make video surveillance more versatile and affordable than ever before. Many solutions available today, however, suffer from remaining impairments.

Remaining Impairments to Coverage and Quality

Although wireless networks are ideal for video surveillance applications, one challenge remains: scalable capacity. Most all-wireless network solutions today simply fail to scale without compromising performance, availability or some other critical requirement, particularly the quality of service for video traffic constantly streaming from the many cameras involved.

The scalable capacity challenge confronting the wireless industry is deeply rooted in the very nature of wireless networking, and has twin components. The first involves the fundamental inefficiencies of shared media communications, which for wireless networks is the radio frequency (RF) spectrum. The second component derives from the limitations inherent in link level wireless protocols that are imposed by bridging or switching, which have adverse consequences for network flexibility, scalability and performance.

To overcome the scalable capacity and performance limitations inherent in a large, flat link level network, WLAN equipment vendors normally employ a wired infrastructure to support the many wireless access points. In a pure wireless network, however, the many inter-node communications are also wireless. Which is why most wireless mesh vendors claim to use some form of “routing” among all nodes. But such “routing” is really nothing more than an extension to the restrictive bridging or switching designed for link level networks.

The reason most wireless equipment vendors have not implemented full network layer routing is a familiar one: cost. Routing protocols are complex. Regularly exchanging route information can consume precious wireless bandwidth. In large networks routing tables can grow correspondingly large, requiring a considerable amount of memory. Constantly updating routes and making packet forwarding decisions in real-time demands substantial computation resources. Because network layer routing can undermine the price/performance of a vendor’s offering, most choose instead to “route” at the link level.

First-generation wireless mesh networks, immediately encountered these limitations, especially with single-radio solutions that suffer from substantial self-interference caused by the relative close proximity of nodes. Next-generation solutions have overcome this problem somewhat with the use of separate radios for access and backhaul; some now even employ multiple radios for backhaul and use directional antennae to minimize the self-interference. Nevertheless, the link level nature of wireless communications can still have a detrimental effect on throughput that accumulates with each hop, severely restricting available bandwidth end-to-end. And even in those wireless solutions where such throughput degradation has been minimized, one final limitation on scalability remains: the “flat” topology of bridged or switched wireless networks. So while multi-radio, multi-channel backhaul may be necessary, it is not sufficient.

The limitations on aggregate bandwidth in some wireless network solutions can severely restrict the number of cameras that can be deployed. Contention for bandwidth also causes an increase in packet loss, packet reordering and packet jitter, which are particularly problematic for real-time applications like video surveillance. The causes and effects of each of these impairments to video quality warrant a closer look.

Packet Loss – Voice and video traffic is normally transmitted in both wired and wireless networks using the connectionless User Datagram Protocol (UDP) because these real-time applications cannot normally benefit from the retransmission feature of the connection-oriented Transmission Control Protocol (TCP). When packets are "lost" or corrupted in a standard UDP data stream they are simply that: lost, never to be recovered. Uncompressed video signals are reasonably tolerant of a modest percentage of packet loss, but any amount of packet loss for compressed video signals becomes noticeable—often in annoying ways. And owing to the relatively limited bandwidth available in wireless networks, some form of compression is always preferred. In wireless networks, traffic loss can be significant owing to periodic congestion, causing packets to be dropped, or transmission errors that corrupt packets, which can be caused by a link data rate that is too high, external RF noise or interference, antenna misalignment, moving obstacles, multi-path fading, user mobility, or a low or variable Receive Signal Strength Indication (RSSI).

Packet Reordering – Packets often arrive at their destination in a different order than they are sent from the source. TCP has the ability to reorder these packets into their original sequence, but UDP does not. With UDP applications, packets are "consumed" in the order they are received. And with compressed digital video signals the effect of packet reordering can actually be worse than the equivalent amount of packet loss because an out-of-sequence packet disrupts the decoding process. For this reason, video equipment is often designed to simply drop the packet, or with high-end systems, to build-in some delay in the decoder to create a brief window of opportunity for reordering out-of-sequence packets. The amount of packet reordering in a routed network is normally less severe of a problem than packet loss, and is usually caused by a change in the end-to-end route during the session. Routes generally change for two reasons: link failures that require rerouting, or link congestion that triggers load-balancing along new paths.

Packet Jitter – Without some provision in the video decoder, jitter (or variations in the arrival rate of packets) causes quality to degrade with noticeable "pixilation" or blurring of the image. The same delay built into sophisticated video equipment to create a window of opportunity for packet reordering also facilitates the removal of jitter from the incoming packet stream; this capability is often referred to as a "dejitter" buffer in decoding systems. The sources of packet jitter in a wireless network include variations in delay at the source, variable link data rates along the path, changing traffic conditions in QoS queues, changes in end-to-end routes, the non-deterministic effects of the CSMA/CA protocol, and roaming, where applicable.

It is important to note that compression algorithms commonly used in digital video applications are stateful; that is, the arriving bit stream is used to make changes in the existing image rather than construct a new image during each frame interval. Stateful compression algorithms have the advantage of being highly efficient, which is highly desirable in a wireless network. But they have the disadvantage of not being tolerant of packet loss, and often require a disruptive resynchronization between the encoder and decoder when packet loss, reordering and/or jitter become severe enough.

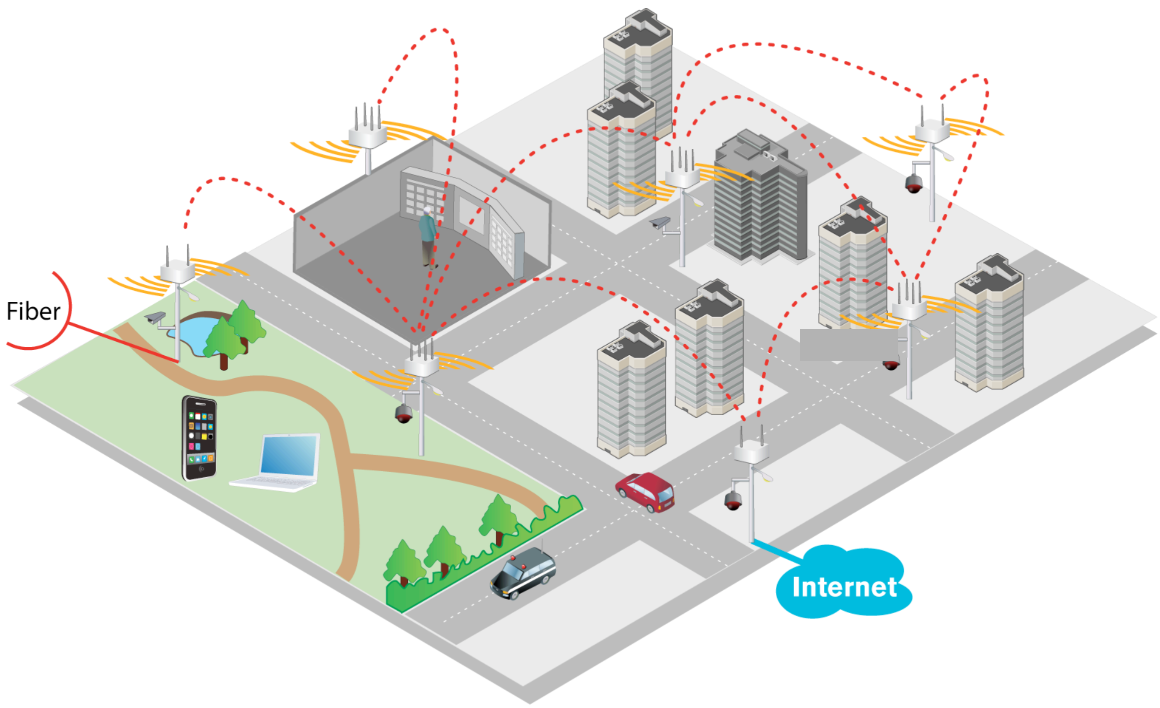
Wireless Routing Enables Ubiquitous Coverage

To overcome the remaining impairments to scalable capacity in all-wireless networks, Azalea Networks has made a significant investment to advance the state-of-the-art in three related areas:

- Creation of an efficient network layer routing protocol purpose-built for multi-radio wireless networks that delivers a scalable, load-balanced combination of high throughput and low latency over multiple wireless hops
- Traffic shaping with special quality of service enhancements that deliver "high definition" video for surveillance and other applications
- The addition of a high-speed roaming capability both within a single IP domain and across multiple domains that seamlessly integrates IP routing with wireless link level access

These advances, combined with enhancements in multi-radio backhaul, security, manageability and other areas, make the Azalea broadband wireless network infrastructure ideally suited for any application that must support video surveillance, especially in public safety, public transportation, oil and gas, and logistics applications. The traffic shaping system (see next section for details on

Active Video Transport) delivers the best available video quality for ordinary video surveillance cameras, monitors and recording systems. Support for fast and seamless roaming enables both cameras and monitoring/recording equipment to be mobile. Additional advantageous features in video surveillance applications include support for long-range directional links, seamless roaming for mobile cameras and monitors, high security, prioritized quality of service to accommodate other applications, and the superior scalability and load-balancing afforded by wireless routing. And Azalea has managed to deliver these and many additional advantages of network intelligence in a solution with a total cost of ownership comparable to or less than that of other offerings.



Azalea supports convergence of voice, video and data applications onto an intelligent and scalable broadband wireless network infrastructure that delivers superior performance, seamless roaming, enhanced quality, carrier-grade security and reliability, and more.

Adaptive Wireless Routing

The only way to eliminate the remaining impairments to wireless network capacity and quality is to implement an end-to-end network layer wireless routing protocol. And this is exactly what Azalea Networks has done with the Adaptive Wireless Routing (AWR) protocol that seamlessly integrates network level routing with link level LANs and physical media (both wireless and wired) communications. AWR has advanced the state-of-the-art by combining the efficiency of distance-vector routing with significant enhancements for wireless link state awareness to create the industry's first network routing solution purpose-built for scaling broadband wireless infrastructures.

As a dynamic, distributed routing protocol purpose-built for wireless networks, AWR is able to forward packets at near nominal wireless data rates across multiple hops with a per-hop latency of under two milliseconds. And even though AWR is a robust routing protocol, it is remarkably efficient, enabling it to be implemented cost-effectively on wireless nodes with multiple radios.

To optimize distance-vector routing for wireless networks, Azalea made three enhancements to the basic protocol. The first is the incorporation of link state awareness to create a quality metric specific to wireless communications. The second is a wireless accommodation for something not possible in wired networks: mobility. AWR supports wireless mobility with fast and seamless roaming capabilities both within a single IP domain and across multiple domains (see sidebar on Motrix High-speed Roaming). The third enhancement is a “local repair” mechanism that prevents loops from forming in any route tables.

These three enhancements make distance-vector routing fully effective and efficient in Azalea’s broadband wireless network infrastructure, where the traffic load is constantly being balanced to optimize performance even under adverse conditions caused by external interference or other momentary disruptions. In addition, AWR supports multicasting to provide more efficient bandwidth utilization for applications that “broadcast” to multiple destinations, as is often the case with video. And by making all packet forwarding decisions in a cross-layer fashion, AWR is able to deliver superior service quality to all applications (see section on Traffic Shaping Delivers “High Definition” Video Quality below).

Motrix™ High-Speed Roaming

Motrix—a contraction for the mobile matrix characterizing the ability to roam seamlessly—builds on AWR’s intelligent network routing capabilities to provide cross-IP subnet roaming among all access points. No other wireless networking solution available today makes roaming as fast, transparent and effortless. The “session persistence” provided by completing handoffs in less than 50 milliseconds enables Motrix to support high-speed roaming from vehicles (ideal for satisfying the needs of public safety and transportation agencies), as well as the most demanding of applications, such as real-time video surveillance where it is often advantageous to mobilize both cameras and monitors.

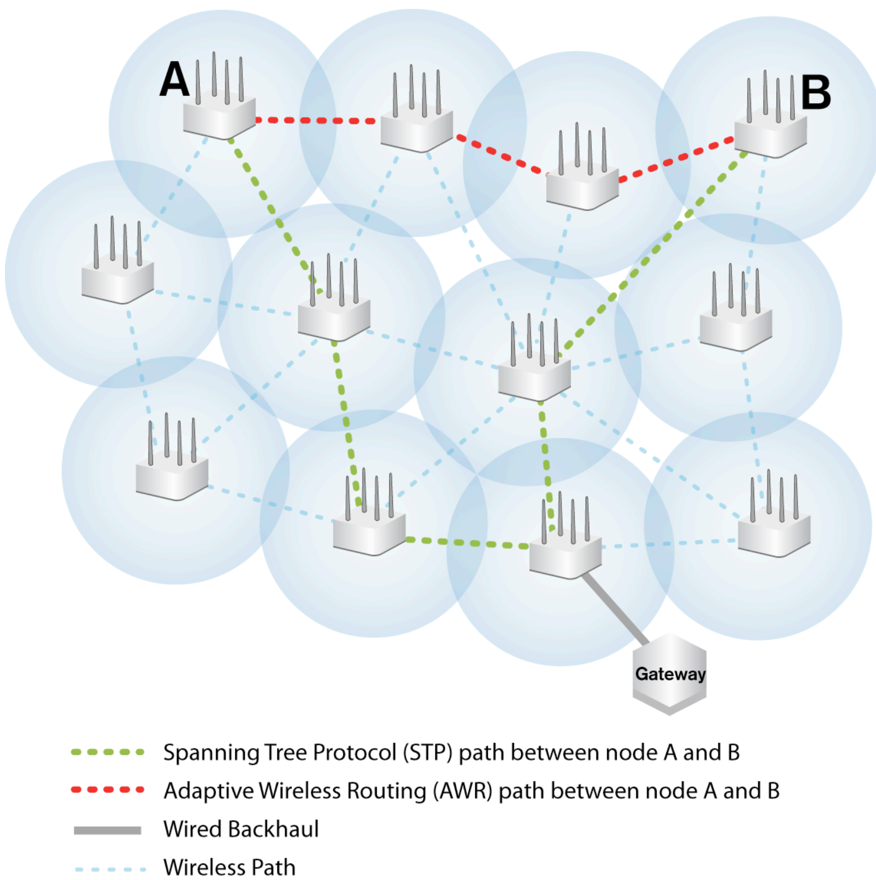
AWR is fully compatible with Wi-Fi standards at both the data link and physical layers, where Azalea has made additional enhancements to further optimize routing in wireless network infrastructures. At the data link layer, AWR overcomes the limitations caused by access contention, and Azalea supports up to four independent, software-configurable radios in a single node with each operating in either access point mode or backhaul mode in the unlicensed 2.4 GHz or 5 GHzbands, or in the licensed 4.9 GHz band (U.S. Public Safety). Naturally, AWR’s network intelligence is able to take full advantage of this powerful multi-radio, multi-path topology in its route creation and packet forwarding decisions.

Azalea also implemented four performance-related enhancements to the basic IEEE 802.11 a/g standards that together optimize bandwidth utilization. Because these enhancements operate only in the backhaul links across the broadband wireless network infrastructure, the access point in any node remains fully compliant with the 802.11 a/b/g standards to maintain interoperability with all Wi-Fi clients. The four enhancements include:

- *Data rate control* that provides the ability to improve overall throughput by making an intelligent tradeoff between transmission speed and the error rate caused by factors like interference and low signal-to-noise ratios.
- *Static channel binding* that enables two standard 20 MHz channels to be bound together to operate effectively as a single channel with twice the throughput capacity.
- *Fast frame formation* that overcomes the inefficiency caused by the mismatch in frame sizes between Ethernet (1500 bytes) and wireless LANs (4096 bytes) by combining contiguous Ethernet frames into a single wireless packet.
- *Hardware compression* that reduces the size of packets with redundant payload content using an efficient and lossless algorithm.

At the physical layer, AWR takes into account the RF characteristics that affect link quality to optimize backhaul throughput and transmission range in outdoor deployments. Azalea also supports the use of both omnidirectional and directional antennae, with the latter being preferred for backhaul with their ability to minimize self-interference.

To further optimize performance at the physical layer Azalea has implemented two additional enhancements. The first is a Radio Frequency Management (RFM) module that automatically scans all frequencies and channels to discover all neighboring nodes within range. The RFM module also constantly assesses link quality and monitors link status, and makes this information—which is critical to optimizing route creation and packet forwarding decisions—available to AWR. The second enhancement is an Automated Interference Detection and Avoidance (AIDA) module that determines when it would be advantageous to change channels for any access point or backhaul radio experiencing high levels of RF interference. To perform this service, the AIDA module must monitor all channels, including those not currently in use anywhere in the wireless network infrastructure.



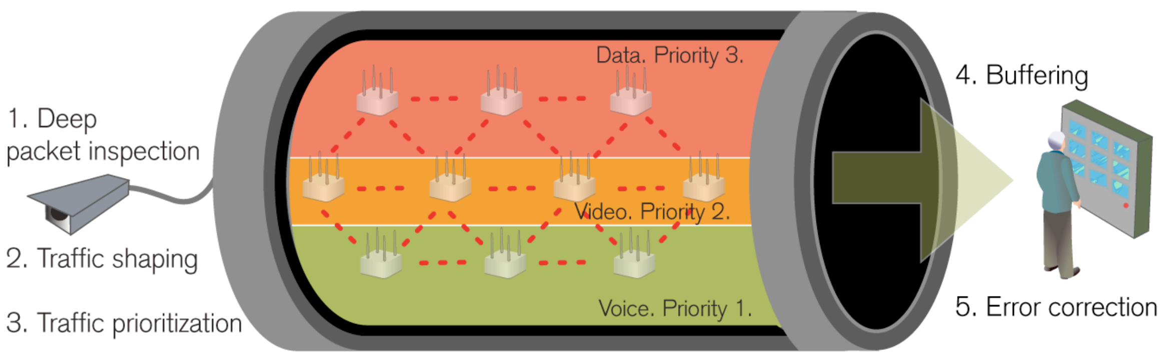
The Adaptive Wireless Routing protocol (AWR) overcomes previous limitations imposed by the spanning tree protocol to make all-wireless network infrastructures more intelligent, scalable, flexible and resilient end-to-end.

The combined effect of these enhancements, all fully integrated at the network, data link and physical layers, is industry-leading intelligence and scalable performance for Azalea's broadband wireless network infrastructure. Tests prove Azalea is able to deliver a significantly higher throughput performance compared to multi-radio solutions that utilize bridging, switching or "routing" at the link layer. Just as importantly, this increased throughput performance is sustained independently of the number of hops from source to destination across the wireless network infrastructure.

Traffic Shaping Delivers "High Definition" Video Quality

Azalea's Adaptive Wireless Routing protocol and related enhancements described in the previous section deliver the high-throughput, low-latency performance that is fundamental to providing satisfactory quality of service (QoS) in converged networks that support voice, video and data communications. Provisions for path and packet forwarding optimization, load-balancing, interference avoidance, and multi-radio backhaul (without any multi-hop throughput degradation) all help ensure the network's ability to sustain peak levels of performance.

To deliver satisfactory QoS, however, a separate layer of intelligence is required to optimize the total throughput performance among all applications supported. Azalea provides this intelligence according to industry standards at both the network and data link layers by integrating support for Differentiated Services (DiffServ), IEEE 802.11e and Virtual LANs. In a routed network, DiffServ is the preferred solution for controlling QoS. The DiffServ architecture specified in RFC 2475 provides a means for classifying and managing network traffic to enhance QoS for critical applications, while maintaining acceptable levels of QoS for all applications. Azalea's implementation takes full advantage of DiffServ's ability to create a hierarchy of categories that enable network operators to minimize latency and/or guarantee a minimal throughput for specified applications by provisioning a preferential allocation of bandwidth. Other, less critical applications, like email and file transfers, are then allocated bandwidth on an as-available, best-effort basis.



Azalea's industry-leading end-to-end QoS provisions, which integrated DiffServ at the network layer with 802.11e and VLANs at the data link layer, facilitate full convergence of voice, video and data communications in an all-wireless broadband network infrastructure.

At the data link layer, Azalea supports both the IEEE 802.11e and 802.1Q (VLAN) standards. Azalea's implementation of 802.11e's wireless LAN QoS enhancements also supports Wi-Fi Multimedia (WMM) or the Wireless Multimedia Extensions (WME) established by the Wi-Fi Alliance. Azalea's solution provides additional flexibility by allowing the priorities established by DiffServ at the network layer to be mapped into the 802.11e flow categories for voice, video, best-effort and background. VLANs enable network operators to create logical partitions on a physical network. In addition to affording a separate layer of security, VLANs are routinely used as another means to help manage QoS. This latter use is particularly valuable in wireless networks because very few Wi-Fi clients currently support the 802.11e standard. Azalea's ability to associate a VLAN ID with a wireless LAN Service Set ID (SSID) enables different DiffServ QoS priorities to be extended to different groups of users and/or applications.

Active Video Transport

Human nature is quite tolerant of delays in video communications, and as long as the delay is consistent, it can be quite long. This explains why satellites continue to be used for television broadcasts even though they were long ago abandoned for telephony. And the reason for the latter is the extraordinary intolerance for delay or latency in voice communications. Even with videoconferencing applications, the intolerance for latency is based on the voice component, not the video component.

Azalea's innovative Active Video Transport (AVT™) traffic shaping solution takes advantage of this aspect of human nature to remove all impairments to video quality, and dramatically improve the performance of video applications in a broadband wireless network infrastructure. Significantly, Azalea's AVT traffic shaping system is able to deliver its "high definition" video even to ordinary laptops and PDAs without any special client software. By taking full advantage of the human tolerance for latency, AVT makes an intelligent tradeoff between latency and the impairments to video quality. The increased latency required to compensate for packet loss, reordering and jitter is imperceptible to users. What is perceptible is the significant improvement in quality.

AVT employs four separate technologies: deep packet inspection, MAC protocol optimization, an in-network retransmission protocol, and an adaptive video jitter removal technology. All four technologies function in unison to deliver enhanced video at up to 30 frames per second end-to-end across the broadband wireless network infrastructure. Deep packet inspection (DPI) identifies and extracts the compression algorithm, video decoding buffer model, video frame type boundary and video timing being used by the packet stream. This information is needed for properly shaping the traffic through the broadband wireless network infrastructure. The MAC protocol optimization and in-network retransmission protocol work together to minimize and, when necessary, recover from packet loss, respectively. This combined prevent/recover approach is especially effective in "noisy" RF environments, where packet loss is normally at its worst. Finally, in addition to removing any jitter, the adaptive video jitter removal technology also reorders any out-of-sequence packets.

The AVT system has both an ingress and an egress function. Video ingress and egress are supported for both gateway and access point nodes, and a single node can provide both ingress and egress for different video streams traveling in opposite directions. Note that because AVT's traffic shaping must function end-to-end across the entire wireless network, this technology is implemented in every node as part of the Azalea Operating System.

- The AVT ingress function is responsible for DPI to identify and characterize video frames, applying the special frame format used by the traffic shaping processes, and interleaving batches of frames during transmission.
- The AVT egress function is responsible for adaptive video jitter removal, issuing in-network retransmission requests upon the detection of both lost and corrupted frames, reordering any out-of-sequence frames (including any retransmitted ones), and releasing the video frames at a consistent, jitter-free rate at the end of the playback deadline.

A demonstration of the dramatic difference in quality with and without Active Video Transport technology is available on the Web at www.azaleanet.com/new-Video-Surveillance.html.

AVT also leverages the multicasting capability built into the Adaptive Wireless Routing protocol to provide concurrent and efficient multi-path transmission of the high-quality video to multiple destinations. This can be particularly useful, for example, in video surveillance applications that require monitoring and/or recording at multiple locations.

The Azalea Product Line

Azalea Networks offers a complete series of both outdoor and indoor wireless routers to deliver seamless coverage in any application. Models are available with up to four radios that can be used for either access or backhaul, and all models are capable of operating in the 2.4 GHz, 4.9 GHz (public safety) and 5 GHz radio frequency bands. When configured for access, the system is fully interoperable with standard IEEE 802.11 a/b/g Wi-Fi clients. When configured for backhaul with external directional antenna(s), transmission range can exceed 16 kilometers (10 miles). Outdoor units have an operating temperature range of -40° to 55° C (-40° to 130° F), and are capable of withstanding winds up to 265 KPH (165 MPH).

Conclusion

Azalea Networks has advanced the state-of-the-art by creating the industry's first routing protocol specifically designed for wireless networking. By bringing unprecedented intelligence to wireless networks, Azalea's Adaptive Wireless Routing protocol and Active Video Transport traffic shaping system combine to overcome the remaining impairments to capacity and quality in video surveillance applications. With Azalea's intelligent broadband wireless network infrastructure, operators get so much more. Superior multi-radio, multi-hop performance. Radio/spectrum-independent routing. Greater flexibility and scalability. Extended range in large geographies. Fast and seamless roaming. "High definition" video quality. Carrier-grade QoS, security and management. And all of this is available at a remarkably low total cost of ownership.

To learn more about how your organization's wireless video surveillance applications can benefit fully from these and other advantages of Azalea's innovative solution, please visit Azalea on the Web at www.azaleanet.com, send an email to sales@azaleanet.com or call 1-408-582-1301; toll-free 866-939-6374.

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