

Dejero *Smart Blending* *Technology*

Delivering reliable connectivity, anywhere

Dejero

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Executive Summary

Dejero *Smart Blending Technology* is a new approach to connection [link] aggregation that delivers both improved reliability and faster aggregate connection speeds compared to other techniques—ultimately enabling important and valuable use cases for broadcast and media companies, public safety organizations, transit and transportation services, and enterprises.

Smart Blending achieves these outcomes by overcoming the technical challenges limiting most traditional connection aggregation solutions.

In particular, Smart Blending uses granular, packet-based data distribution, enabled by real-time measurements of connection characteristics and enhanced by adaptive buffering and application acceleration. This design avoids the drawbacks of solutions that maintain flow stickiness and delivers superior performance with asymmetric connections like 4G LTE, 5G, and satellite—making it especially valuable in mobile and nomadic situations.

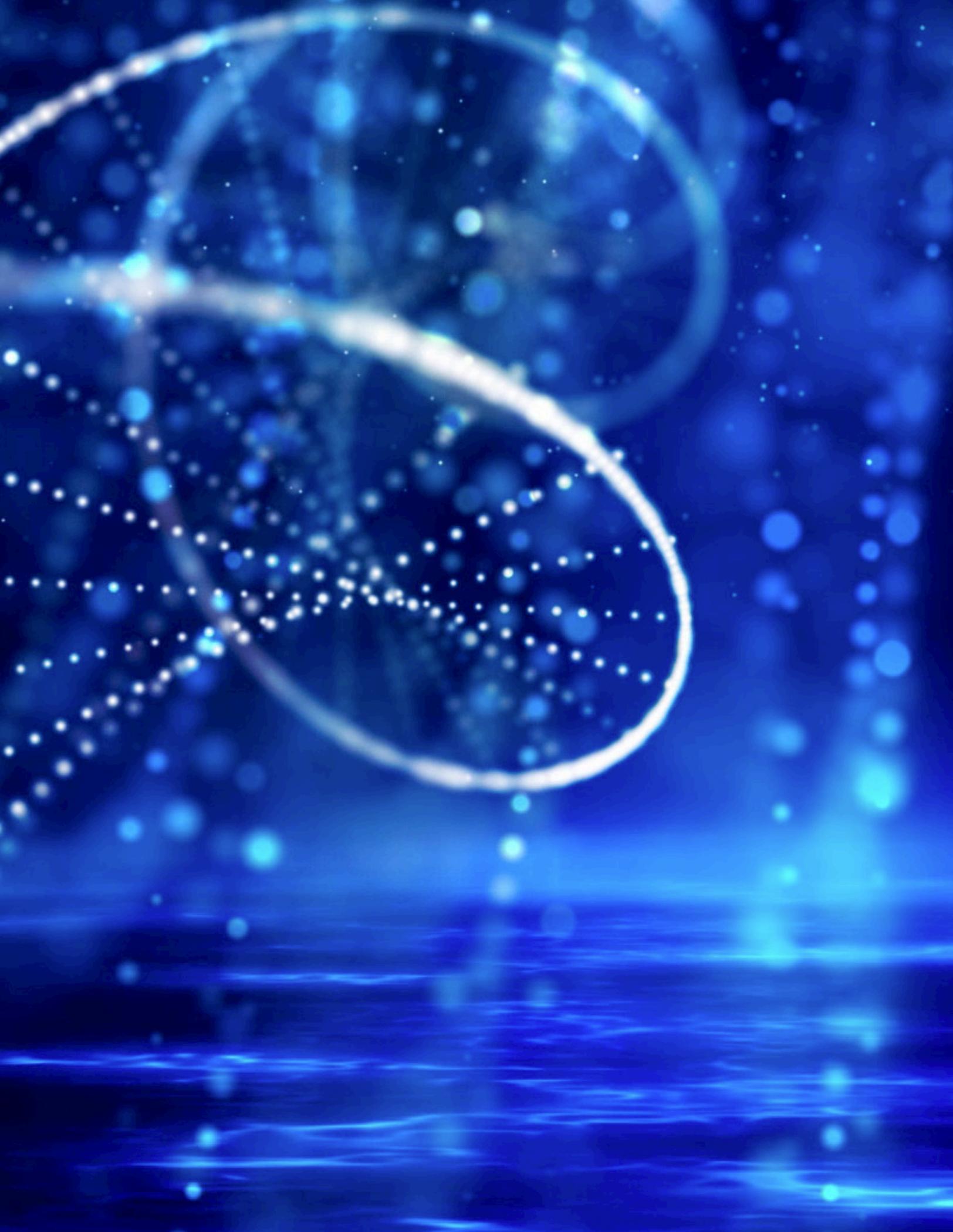
As an alternative or enhancement to traditional connection aggregation (for example, in SD-WAN deployments), or as a viable option where other solutions are inadequate, Smart Blending delivers significant advantages, including:

1. Achieving high link utilization and performance even with only a single flow, and even with unreliable connections
2. Enabling particularly demanding applications, like low-latency constant bitrate video streaming
3. Simplifying operational management and improving failover performance
4. Administratively configured connection priorities that dynamically and adaptively use the available links (in priority order) to achieve the target blended bitrates

Moreover, Smart Blending's containerized, software-based approach abstracts underlying connectivity, enabling end-to-end (including the access edge) orchestration of application-aware network services.

All of these elements combine to allow Dejero *Smart Blending Technology* to deliver reliable, lower-cost Internet and cloud connectivity while still meeting demanding quality of service needs—in other words, to deliver reliable connectivity, anywhere.

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Introduction

Reliable network connectivity is a must-have for most businesses and organizations today. Increasingly, though, this requirement is extending to reliable connectivity anywhere, as workforces become more mobile, as additional customer demands emerge, and as technology unlocks new and valuable use cases.

Reliable connectivity *anywhere* unlocks important and valuable use cases for a wide range of markets—including broadcast and media, public safety, enterprise, and transit and transportation

Connection aggregation—combining multiple available connections to deliver the improved reliability, speed, and quality—is both a response to, and an enabler of, this need for reliable connectivity anywhere: as organizations extend into more challenging locations, they depend on connection aggregation to meet their reliability and quality requirements; and, as connection aggregation technology matures, it creates new opportunities for organizations at the vanguard of technology adoption.

Connection aggregation technologies combine multiple links into a single virtual network connection

For instance:

- **Broadcast and Media** companies can transport video and data reliably from virtually anywhere, no matter how remote or mobile
- **Public Safety** organizations gain enhanced real-time situational awareness and response capabilities even when networks are stressed
- **Transit and Transportation** services can enable streamlined vehicle data transmission, even at high speeds and across large geographies

- **Enterprises** gain the ability to keep their branch locations and mobile workforce reliably connected, without relying on expensive dedicated links¹

Connection aggregation improves the delivery of all of these services, and extends coverage to practically anywhere by combining many links—even those with asymmetric characteristics, jitter, and different latencies and bandwidth—into a single, reliable connection.

'Traditional' connection aggregation solutions were built for a world of fixed locations using wired broadband technologies

Practical Limitations of 'Traditional' Connection Aggregation

Broadly, 'traditional' connection aggregation solutions can provide sufficient quality for stationary applications using wired broadband technologies including fiber, DSL, and cable. But even in this scenario the aggregation doesn't make efficient use of the network resources, negatively impacting connection reliability, speed, and efficiency.

To meet the reliability and speed requirements of many services, wireless technologies must be added to the mix—even for stationary locations

Faced with significant technical hurdles, traditional connection aggregation solutions typically keep each flow 'sticky' to a single link. However, this approach trades performance for implementation simplicity—a minimum threshold of capabilities is reliably delivered, but never at the full potential of all the connections—leading to suboptimal performance and an inefficient use of resources.

¹SD-WAN only partially addresses the needs of enterprises; the shortcomings of traditional SD-WAN solutions are examined in detail in the *Dejero whitepaper Enhancing SD-WAN Performance—Overcoming the challenges limiting connection aggregation in traditional SD-WAN solution*

But that's only part of the problem: to meet the ever-increasing reliability and speed required by many connected applications and services, wireless technologies such as Wi-Fi, cellular (for instance, 4G LTE, 5G), and satellite must be added to the mix, even for stationary applications and head offices.

Unfortunately, the limitations of traditional solutions are exacerbated by wireless technologies, which often exhibit significantly variable latency and major differences in bandwidth capacity (which itself varies over time)—and for remote, mobile, or nomadic sites, the aggregated connection might depend entirely upon these less reliable (compared to fixed access), more variable technologies.

Techniques created for stationary applications and wired networks are ill-suited where link characteristics vary over time and by connection, and where connections are shared

In short: connection aggregation techniques created for, and in a world of, stationary applications and wired networks are extending into environments where connections exhibit significant time variation in terms of throughput, latency, and packet loss, and where connections are shared, rather than dedicated. This extension reveals limitations that must be addressed so that organizations can truly and confidently benefit from reliable connectivity, anywhere.

A Superior Alternative: Dejero *Smart Blending Technology*

In stark contrast, Dejero *Smart Blending Technology* delivers reliable connectivity anywhere, providing the reliable first- and last-mile connectivity required for cloud computing, online collaboration, the secure exchange of video and data, and other demanding applications.

Smart Blending allows organizations to effectively, efficiently, and reliably leverage the combined capacity of their individual links, even when those links have different and variable bandwidth and latency, and even when those links span multiple access technologies.

Dejero *Smart Blending Technology* lets organizations leverage the full combined potential of their individual links—even when those links have different and variable characteristics

In particular, and unlike most traditional connection aggregation solutions:

- Individual flows can achieve significantly higher utilization of the maximum aggregated bandwidth of all the links, because a flow can be transparently split across all available links while presenting a consistent 4-tuple²
- Failure of a link does not cause flows to terminate, timeout, and reestablish, because the 4-tuple remains unchanged
- Because the solution dynamically accounts for link variability, individual flows can be efficiently split across links with different and variable bandwidth capacity, and across links with different and variable latency
- Bufferbloat is dynamically detected and actively avoided, to keep latency close to the base propagation delay of the aggregated connections

Additionally, Smart Blending has the operational advantage that new connections can be added dynamically, without needing reconfiguration by an administrator, because the state of the connection (up versus down) and connection characteristics are discovered automatically.

This paper explains how Smart Blending works, and shows how it overcomes (or completely avoids) the technical challenges limiting traditional connection aggregation approaches.

Smart Blending is engineered to be best-in-class at supporting multiple connection types and to dynamically select paths for load sharing and resiliency

² Both TCP and UDP use a '4-tuple' to identify a distinct conversation (a 'flow') between two hosts: {Source-IP, Source-Port, Destination-IP, Destination-Port}

Dejero Smart Blending Technology

A major difference between Dejero *Smart Blending Technology* and traditional connection aggregation techniques is that Smart Blending measures dynamic connection characteristics in real time and intelligently splits flows across multiple connections on a packet-by-packet basis. This approach differs fundamentally from the approach used in traditional solutions, in which links are assumed to have static characteristics and flows are kept 'sticky' to an assigned link.

Smart Blending measures dynamic connection characteristics in real time, allowing it to intelligently split flows across multiple connections on a packet-by-packet basis

The result with Smart Blending is that organizations are able to effectively, efficiently, and reliably leverage significantly more of the aggregate capacity of their individual links, even when those links have different and variable capacity and latency.

The next three sub-sections explain how Smart Blending delivers these outcomes: first, we introduce the architecture; then, we explore how individual connections are managed in the aggregation algorithm; finally, we present additional features that help to further optimize performance.

The architecture consists of a remote terminal in the field [Dejero GateWay network aggregation device] linked to an endpoint in the cloud [Dejero GateWay Cloud Service]—very similar to cloud-based SD-WAN

Deployment Architecture

The Smart Blending architecture consists of two main components (see Figure 1):

1. A remote gateway terminal (for example, at a branch office, a mobile site, a nomadic location, etc.)—called a Dejero GateWay network aggregation device
2. A network service end-point hosted in the cloud—called the Dejero GateWay Cloud Service

The Dejero GateWay device supports multiple links and creates a tunnel through each link between the GateWay device and the GateWay Cloud Service.

To provide the high performance and resiliency needed by today's demanding applications and use scenarios, Dejero GateWay Cloud Services are implemented as a containerized and orchestrated cloud-based offering. This design delivers high reliability and works particularly well for cloud-hosted SaaS applications where data ingress and egress to and from the GateWay Cloud Services are already cloud-based.

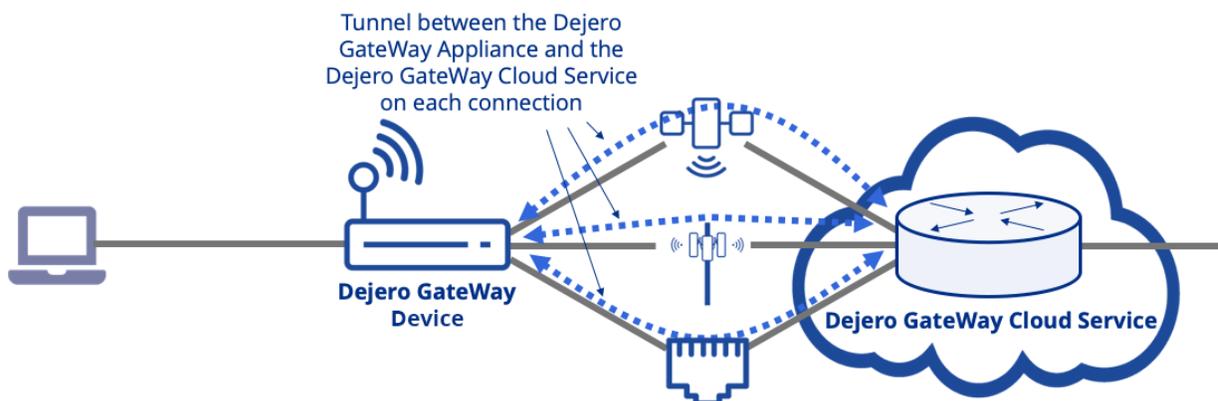


Figure 1— Dejero *Smart Blending Technology* deployment architecture

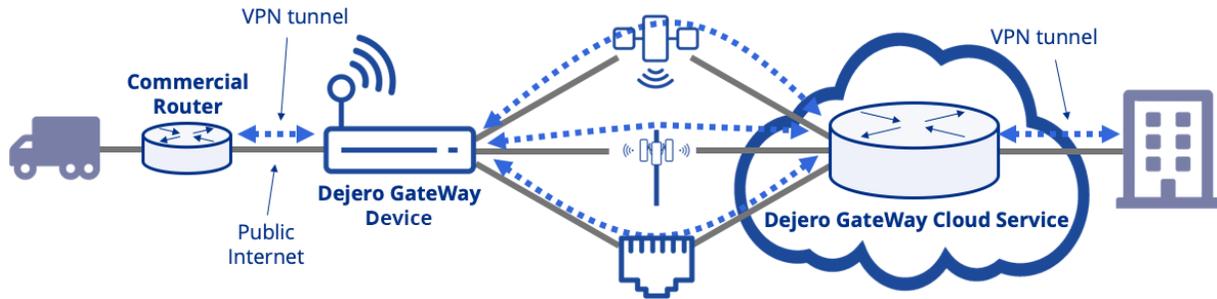


Figure 2 – Typical Dejero *Smart Blending Technology* deployment with external commercial router

Dejero GateWay Cloud Services are implemented as a containerized and orchestrated cloud-based offering

Aggregating Connections at Field Locations

IP flows are ‘split’ at one and ‘blended’ at the other, working symmetrically in both directions.

In the scenario in which connections are aggregated at a field location, IP flows generated by devices plugged into the “LAN” port of the GateWay device are split across the tunnels over the available links, where network address translation assigns an IP belonging to the GateWay Cloud Service before egressing to the Internet. By assigning a single cloud IP address, this architecture allows flows to remain unbroken even if the links ever fail or change IP addresses.

Dejero *Smart Blending Technology* ‘splits’ flows at one end and ‘blends’ them at the other, working symmetrically in both directions

Smaller deployments—for example, a mobile or nomadic team, or a small branch office—can use a Dejero GateWay device in conjunction with a commercial off-the-shelf router/firewall (see Figure 2).

In this setup, the firewall/router directs traffic either through the VPN tunnel or directly on the LAN port of the GateWay device, depending on its routing table. The GateWay device is responsible for splitting both types of traffic—the plaintext and VPN-encrypted—over the available connections.

Smaller deployments—like a mobile or nomadic team, or a small branch office—can use a Dejero GateWay network aggregation device in conjunction with a commercial off-the-shelf router/firewall

For larger deployments that are part of an existing software-defined wide area network (SD-WAN), integrating with a Dejero GateWay device is achieved in a similar manner (Figure 3). From the perspective of the SD-WAN router, there’s only a single public Internet link that is composed of the underlying, blended connections.

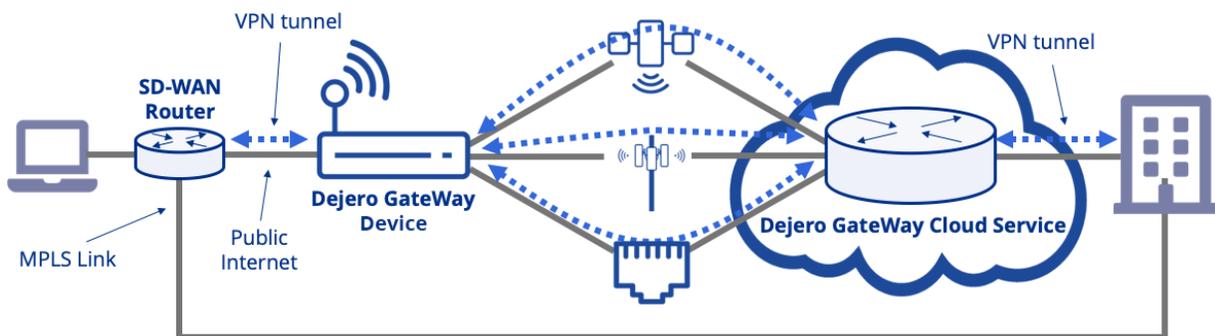


Figure 3 – Dejero *Smart Blending Technology* integrated with existing SD-WAN

Larger deployments can easily leverage an existing SD-WAN implementation

Aggregating Connections at the Central Office

Unlike traditional solutions, which require complex routing and eBGP configurations, aggregating multiple connections at the central office via Dejero *Smart Blending Technology* is just a mirror of the field implementation: a Dejero GateWay device at the central office opens tunneled connections to the Dejero GateWay Cloud Service over each of the available links (see Figure 4).

With Dejero *Smart Blending Technology*, the central office deployment is just a mirror-image of the field location: no eBGP required!

A fixed/static IP address (or a larger address space, if required) can be assigned by Dejero, so that incoming connections can be accepted from the field locations.

The GateWay device is responsible for optimally splitting and blending the connections for the public Internet and VPN encrypted traffic.

Combining Smart Blending with an SD-WAN deployment delivers the best of both worlds, with each piece excelling at important functions

As with the field deployment, the Dejero GateWay device can be deployed alongside an existing SD-WAN router to deliver the best of both worlds: the Dejero GateWay device provides effective, efficient, high-performance blending of connections that are dynamically added or removed, all with potentially extremely different characteristics; the SD-WAN manages the network configuration between locations.

Connection Profiling and Management

Achieving high performance results while avoiding the issues holding back other solutions demands meeting particular requirements; the subsections that follow explain some key features and characteristics of Dejero *Smart Blending Technology*.

Real-Time Performance Monitoring and Blending Asymmetric Connections

To account for the dynamic behavior networks, connection characteristics—including throughput, latency, and packet loss—are measured in real time.

Measuring connection characteristics in real time unlocks a range of capabilities unavailable in traditional solutions

This feedback loop allows both the GateWay device and the GateWay Cloud Service to operate with fine granularity as they determine the best link over which to send a particular packet.

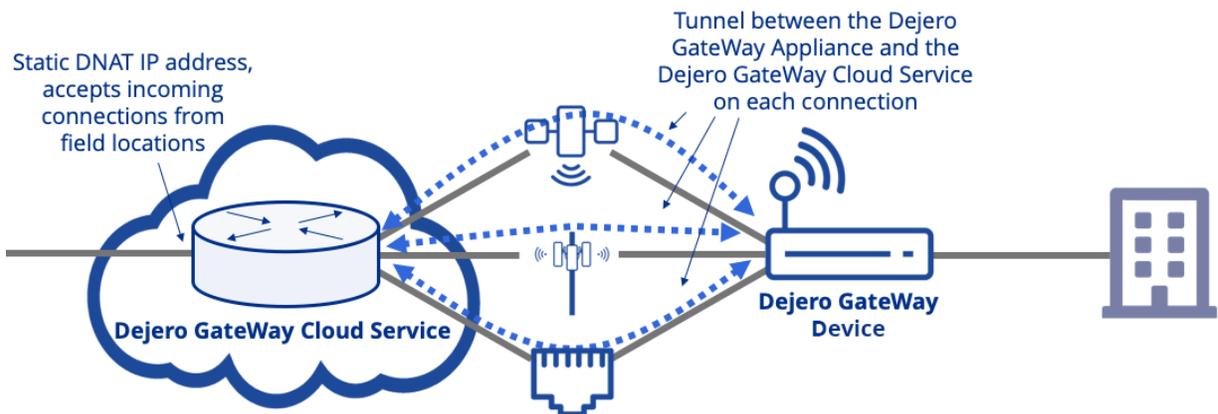


Figure 4 – Central office routing with Dejero *Smart Blending Technology* is just a mirror image of the field location deployment

To blend connections in both the transmit and receive directions, neither the GateWay device nor the GateWay Cloud Service make any assumptions about connection performance symmetry.

To blend connections in both the transmit and receive directions, Dejero *Smart Blending Technology* doesn't make any assumptions about connection performance asymmetry

Measuring dynamic connection characteristics is vitally important for managing the connections in general, but is especially so for networks where performance is asymmetric—for instance, cellular networks, in which the download performance is often significantly faster than the upload performance.

Importantly, the data usage for these real-time insights is minimized by 'piggybacking' the measurement on top of application data wherever possible. If a connection lacks sufficient application data to properly characterize the performance, then data is adaptively incorporated to ensure persistent excitation and to improve identifiability.

By statistically filtering these real-time measurements, Smart Blending assesses the performance and reliability of connections; those connections deemed unreliable are put into a state where they transmit redundancy only (for example, forward-error correction, duplicates of packets transmitted on other connections, etc.). While in this state, the real-time measurements continue to be piggybacked on the redundant packets, allowing both the GateWay device and the GateWay Cloud Service to determine when the connection can be reincorporated into the pool of useful connections.

Dynamic Connection Management

This approach also allows connections to be added dynamically without the need for reconfiguration or measurement/calibration by an administrator.

As soon as a connection is observed by the system (meaning that the link status is up and an IP address is assigned), Smart Blending begins probing to

assess the connection's performance and reliability, then automatically adds it to the blending pool when it will provide benefit.

Connections are dynamically added to, or removed from, the aggregate pool without needing reconfiguration by an administrator

Administrative Preferences

Administrative preferences and hints can also be incorporated into the blending algorithm.

For example, the *Priority Routing* feature allows more costly connections to be used only when necessary; this approach lets Smart Blending maintain a specified throughput by using low-cost connections whenever possible and only using higher-cost connections when less expensive connections are unable to meet the configured throughput.

This connection prioritization differs from failover, where complete failure of the link is required before the lower priority connections are engaged.

The *Priority Routing* features reserves more costly connections until they're absolutely necessary to maintain a specified throughput

Additional Optimizations

Dejero *Smart Blending Technology* incorporates additional optimizations to maximize application performance in the face of real-world challenges.

Flow/Application Acceleration

When TCP and UDP flows are split across connections with different properties, the respective congestion control algorithms³ introduce complexities that can inadvertently undermine performance.

To directly address these issues, Smart Blending incorporates accelerators that act either on a flow/application, or on a class of application (for UDP).

³ TCP implements congestion control at the protocol layer, while UDP relies on the applications to do so

Smart Blending also improves performance through flow/application accelerators that account for congestion control behavior, ensuring that congestion control algorithms don't see premature or mistaken indications that link capacity has been reached

These accelerators account for congestion control behavior to ensure that the sender's congestion control algorithm never sees premature or mistaken indications that it has achieved link capacity.

For example, TCP flows are accelerated using transparent proxying techniques. The TCP flow is no longer end-to-end, but is instead terminated just before the splitting occurs; the accelerator acknowledges the data from the sender on behalf of the ultimate destination, then ensures reliable transmission over the blended links. As a result, the sender's congestion control algorithm never sees premature indications of reaching link capacity.

The solution also incorporates additional approaches that accelerate the performance of UDP flows based upon application class—particularly for the types used for live video contribution and distribution, which traditionally demanded a large-capacity MPLS link for reliable transmission.⁴

For instance, in these scenarios Smart Blending adaptively trades off latency to add ARQ and tight jitter control to these types of flows when they're transmitted over potentially unreliable public Internet links (for example, wireless connections). The net result is that the application experiences a more stable connection; the tradeoff is that the application may experience higher latency⁵—but this result tends to be acceptable for many video distribution and contribution scenarios where two-way interactivity isn't required.

In addition to enabling Smart Blending to split individual flows across multiple links, these accelerators also enable very specific and demanding applications, like reliable low-latency constant-bitrate video streaming, in scenarios in which the combination of connection, protocol, and application would otherwise create significant issues.

Bufferbloat Management

Buffering is a normal behavior and allows a network resource (for example, a router, a CMTS, a DSLAM, an eNodeB, etc.) to gracefully handle bursts of traffic by increasing latency slightly rather than dropping packets; however, excessive buffering (bufferbloat) can lead to high latency as queues fill and, ultimately, can cause packet drops.

Bufferbloat occurs when a sender sustains transmission through the connection buffer faster than the buffer's drain rate, causing the buffer to completely fill (see Figure 5).

This behavior fills the output queue of the network resource, and the queue is left as a standing buffer even after the sender backs off to the drain rate—in extreme cases, packets are dropped at the input to the buffer.

Most connection aggregation algorithms don't explicitly target bufferbloat, and instead rely on other components in the system to handle it (if at all). For example, these alternatives might assume that:

- The originating sender of the data could detect the standing buffer and attempt to drain it by sending data at a lower rate
- The upstream router could use active queue management algorithms to drop packets before the standing buffer can fully form

In contrast, Dejero *Smart Blending Technology* detects and actively reduces bufferbloat, which is important to preserving performance—especially so if all other components in the system cannot.

⁴ Dejero's strong background in blending cellular and other IP connections to enable high-quality contribution and distribution of live video underlies much of Dejero's *Smart Blending Technology* in this regard

⁵ More specifically, the worst-case latency seen is determined by the highest latency in the pool of connections—so, if a flow was already using only the single connection with the longest latency, then its latency would not increase

Unlike most connection aggregation solutions, Dejero *Smart Blending Technology* detects and actively reduces bufferbloat to maintain latency close to the base propagation delay

In scenarios in which the Dejero GateWay device is the bottleneck link, it minimizes the amount of bufferbloat that it introduces by using per-flow active queue management (AQM) techniques. The device distinguishes between 'good' queues (temporary queues resulting from large bursts of traffic) and 'bad' queues (standing queues that never clear, only adding latency to a flow); 'bad' queue packets are dropped, providing feedback to senders. Flows that don't respond to drops (relentless senders) are segregated such that they don't introduce latency to other flows.

To address scenarios where the Dejero GateWay device is not the bottleneck link (meaning the bottleneck is one or more of the links), it uses a rate-based congestion control algorithm with feedback to ensure that the latency of the link stays close to its base propagation delay.

Smart Blending is particularly adept at live video distribution—in November, 2018, Dejero was recognized with a prestigious Technology & Engineering Emmy® Award for 'excellence in engineering creativity', honoring a decade of achievements in the field of live transmission

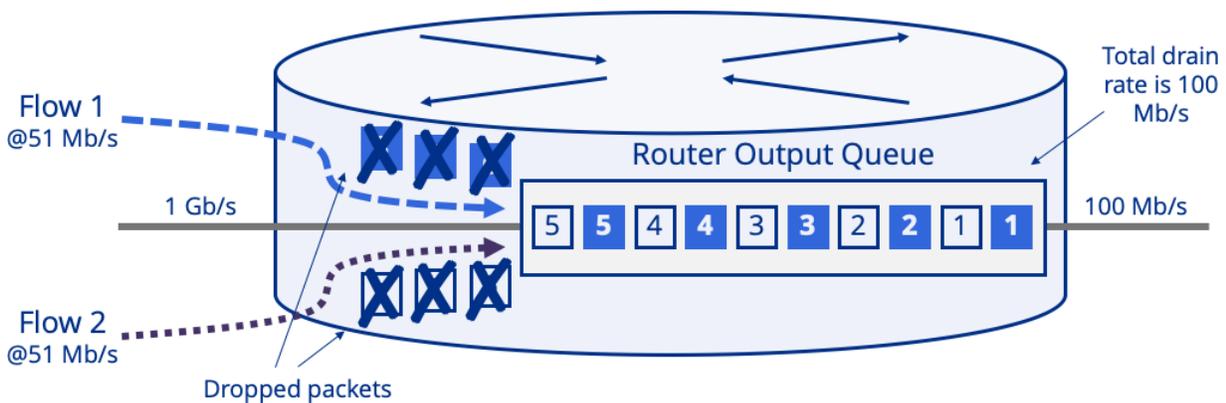


Figure 5 – When the flows try to send more than 100 Mb/s in aggregate, the buffer fills to maximum capacity and packets are dropped

Summary

Dejero *Smart Blending Technology* is a new approach to connection (link) aggregation that delivers both improved reliability and faster aggregate connection speeds compared to other techniques—ultimately enabling important and valuable use cases for broadcast and media companies, public safety organizations, transit and transportation services, and enterprises.

Dejero *Smart Blending Technology* delivers both improved reliability and faster connection speeds, compared to other connection aggregation techniques

Smart Blending achieves these outcomes by overcoming and avoiding the technical challenges that limit most traditional connection aggregation solutions.

In particular, Smart Blending uses a packet-based approach to distributing data across links, enabled by real-time measurements of connection characteristics. This design avoids the drawbacks of solutions that maintain flow stickiness to connections and delivers superior performance with asymmetric connections like 4G LTE, 5G, and satellite—making it especially valuable in mobile and nomadic situations.

Additionally, novel adaptive input and output buffering combined with application acceleration techniques enable connections with significantly different characteristics to be effectively and efficiently used for applications that are very jitter sensitive.

As an alternative or enhancement to traditional connection aggregation (for example, in SD-WAN deployments), or as a viable option where other solutions are inadequate, Smart Blending delivers significant advantages, including:

1. Achieving high link utilization and performance when blending, even with only a single flow, and even with unreliable connections—delivering reliable connectivity that enables a range of applications, even for mobile and nomadic

scenarios dependent upon relatively unreliable connections or connections with significantly different characteristics

2. Enabling particularly demanding applications, like low-latency constant bitrate video streaming
3. Simplifying operational management and improving failover performance by automatically adapting to the addition or removal (including failure) of connections—additions result in an immediate increase to blended capacity; failures are transparent (i.e., outstanding flows remain unbroken)
4. Administratively configured connection priorities that dynamically and adaptively use the available links (in priority order) to achieve the target blended bitrates

Smart Blending is especially valuable for mobile and nomadic locations, which are frequently entirely dependent on variable and asymmetric wireless connections

Moreover, Dejero *Smart Blending Technology*'s containerized, software-based approach abstracts underlying connectivity, enabling end-to-end (including the access edge) orchestration of network services that are application aware.

All of these elements combine to allow Dejero *Smart Blending Technology* to deliver reliable, lower-cost Internet and cloud connectivity while still meeting demanding quality of service needs—in other words, to deliver reliable connectivity, anywhere.

Ultimately, Dejero *Smart Blending Technology* delivers reliable connectivity, anywhere

The Dejero logo is rendered in a bold, dark blue, sans-serif font. It is positioned on the left side of the page, below a large blue graphic that features a stylized fingerprint pattern and a network of dots and lines.

About Dejero

Driven by our vision of reliable connectivity anywhere, Dejero delivers fast and dependable connectivity required for cloud computing, online collaboration, and the secure exchange of video and data.

With our global partners, Dejero supplies the equipment, software, connectivity services, cloud services, and support to provide the uptime and bandwidth critical to the success of today's organizations.

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