# Advanced Frequency Reuse

## More Capacity Out of Current Spectrum

## Introduction

To thrive in the increasingly competitive, hyper-connected world, Network Operators must offer new revenue-generating services while constantly upgrading their delivery capabilities. They are under pressure to offer valuable new services while maintaining a high level of quality of experience throughout their networks.

Operators must rapidly expand the capacity of their networks by adding many new cell sites. They must also offer 4G services and, in the future, 5G, services as these become available. The backhaul network is in a constant state of change.

As backhaul is a major component of sustainable network infrastructure, backhaul spectrum management is a crucial ingredient for success. But lack of backhaul frequencies restricts new cell-site deployment.

*Advanced Frequency Reuse*, based on Ceragon's unique multi-core technology and available on the IP-20 platform, breaks through deployment restrictions, granting Operators the freedom to deploy cell sites wherever and whenever they are needed. It enables reuse of frequencies and the establishment of wider channels as it significantly boosts the capacity of wireless backhaul links.

Advanced Frequency Reuse is the latest innovation from Ceragon for future-proofing networks, eliminating backhaul constraints and granting Operators the power to thrive.

## The Hyper-Connected Mobile World

Mobile devices such as smartphones, tablets, phablets, and laptops are already in common use and are gaining momentum in numbers and power. The massive spread of such devices, along with the spectacular increase in the services they consume, has been the major catalyst for the exponential growth in demand for mobile data, almost doubling in 2014 over the previous year.

Source: Ericsson Mobility Report, Nov 2014

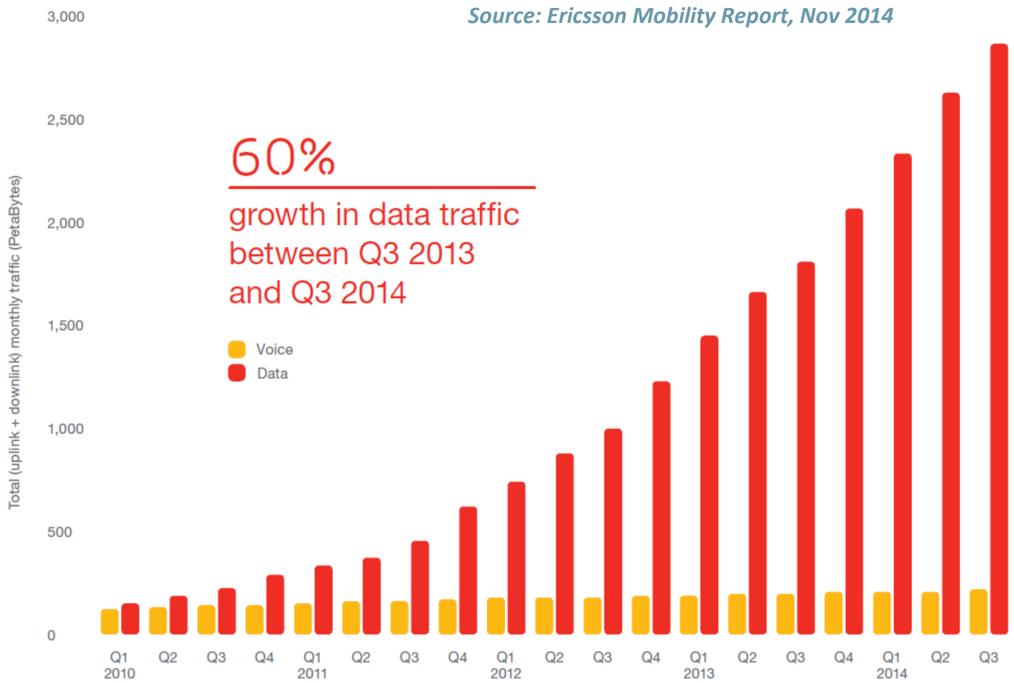



*Figure 1: Mobile data growth*

This trend will accelerate in the immediate future from a surge of wearable devices such as smart glasses with bandwidth-consuming, augmented-reality applications and from multitudes of Internet-of-Things (IoT) devices such as connected cars with bandwidth-intensive navigation and infotainment apps. New apps and services will, on one hand, create new revenue streams for Operators while, on the other hand, impose new bandwidth and latency requirements on networks.

## Effects on the Access Network

As the numbers and uses of mobile devices expand, networks are called upon to supply seemingly endless volumes of capacity. Operators face an unrelenting, steep, uphill battle in their efforts to provide adequate backhaul bandwidth in order to deliver dependable, high quality-of-experience to their bandwidth-hungry user base.

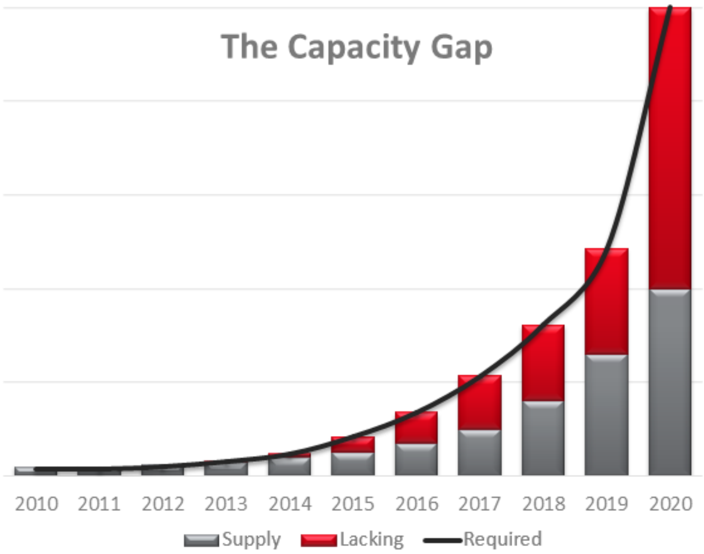
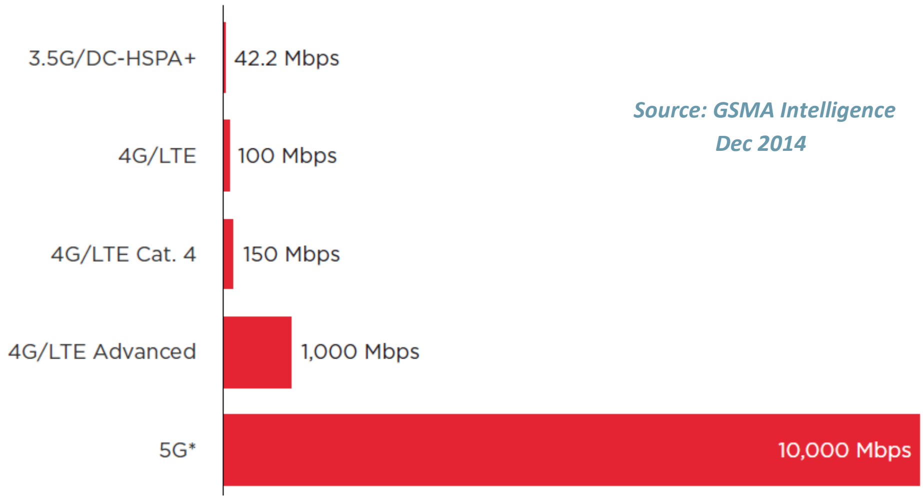



*Figure 2: Capacity gap*

Escalating data demand drives growth in network capacity, the predominant motivator for the evolution of mobile networks along technology generations: 2G→2.5G→3G→3G+→4G→4G+→5G. Today's widespread evolution to LTE and LTE-A networks provides significant weaponry in the Operator's arsenal to deal with massive increases in traffic.




*Source: GSMA Intelligence Dec 2014*

*Figure 3: Maximum theoretical downlink speed by technology generation*

But as the data growth rate irresistibly accelerates, the mere enhancement of radio-access network (RAN) technology is no longer sufficient. A change in network deployment strategies is also required.

Coping with intense capacity pressure calls for more and more segments of the network to move from *planning for coverage* to *planning for capacity*. To provide adequate capacity, a significant number of new cell sites must be added, densifying the network. In addition, the capacity of many of the new, as well as the old sites, must be increased. This is generally accomplished in two ways: **(1)** by evolving to newer-generation technology (resulting in enhanced spectral efficiency) and **(2)** by employing wider frequency channels.

## The Resulting Backhaul Challenges

The effect of demand for capacity on RAN strategies has very significant ramifications for wireless backhaul networks. First, these backhaul networks face certain bandwidth limitations which prevent them from keeping up with capacity requirements. Second, densification necessitates more links between base stations and aggregation points necessitating a pursuit of new spectrum. Let's discuss both of these ramifications in more detail.

### *Coping with Bandwidth Limitations*

Growing cell-site traffic loads the backhaul links to levels far beyond what Operators imagined when those links were first deployed. New backhaul technologies such as LoS MIMO, XPIC, wide channels and ultra-efficient modulation techniques like 2048QAM, together with spectrum-utilization enhancement techniques such as header de-duplication and WRED, significantly increase backhaul delivery capacities. However, these are no longer adequate in the face of skyrocketing demand. A change in the network planning paradigm is necessary.

Deployment of wider frequency channels is required. Expanding from 28MHz channels to 56MHz, 112MHz and even 224MHz-wide channels is a growing trend that allows better utilization of allocated frequency blocks. With wider channels, fewer guard bands are required, allowing more spectrum to be used for actual signal. However, spectrum for these wider bands is not always available or can be quite expensive and time-consuming to obtain.

### *Densification*

Widening the channels of existing links is helpful, but it is only part of the solution. The process of massive densification of cell sites necessitates more backhaul links and an associated concentration of links at aggregation sites. However, a law of physics limits the number of links that can be deployed.

As more links are added, distance between adjacent links necessarily shrinks. As angular separation between links decreases, interference between links using the same frequency increases. Since the minimal angular separation required for reuse of the same frequency is usually from 90$^{O}$ to 75$^{O}$ (the latter, only with expensive Class-4 antennas), the denser environment encounters a lack of available frequencies. As we stated above, these frequencies are often not available or expensive and/or obtainable only after a protracted process.

The lack of frequencies holds back the essential densification of the network and results in service degradation in congested areas. In many cases, expensive and time-consuming fiber infrastructure must be introduced as the only solution while Operators would prefer to avoid that.

## Advanced Frequency Reuse Boosts Capacity Without New Frequencies or Deployments

Ceragon's groundbreaking *Advanced Frequency Reuse* enables Operators to utilize their existing backhaul frequencies to transport far greater capacities than ever before.

Advanced Frequency Reuse enables Operators to use a single existing frequency channel on adjacent links that can be closer together, accommodating densification and promoting the use of wider channels on new and existing links. Since Advanced Frequency Reuse is based on multi-core technology, Operators can also benefit from multi-core's inherent higher gain through the use of smaller antennas, saving additional cost and space.

### *How It Works*

Advanced Frequency Reuse is based on Ceragon's unique multi-core technology. Multi-core comprises an advanced, parallel radio-processing engine built around Ceragon's in-house baseband modem and RFIC chipsets. Optimized for processing of multiple radio signal flows, the multi-core technology hosted on Ceragon's leading IP-20C wireless solution multiplies capacity and increases system gain over current technology.[1]

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[1] More information on Ceragon's unique multi-core technology can be found at: http://www.ceragon.com/images/Reasource_Center/Technical_Briefs/Ceragon_Technical_Brief_FibeAir_IP-20C_Multi-Core_Technology-The_Next_Generation_in_Microwave_Communications_Rev4.pdf

Advanced Frequency Reuse uses revaluated channel parameters to mitigate the interference caused by an adjacent link. While interference naturally increases as angular separation decreases, Advanced Frequency Reuse includes a unique interference-mitigation technique. This is the key to enabling co-existence of low-angle, adjacent links with no fading or quality degradation.

With Advanced Frequency Reuse, the angular separation between links using the same frequency can decrease from $90^{O}$ to as little as $15^{O}$ allowing more links that use the same frequency channel to co-exist in close proximity.

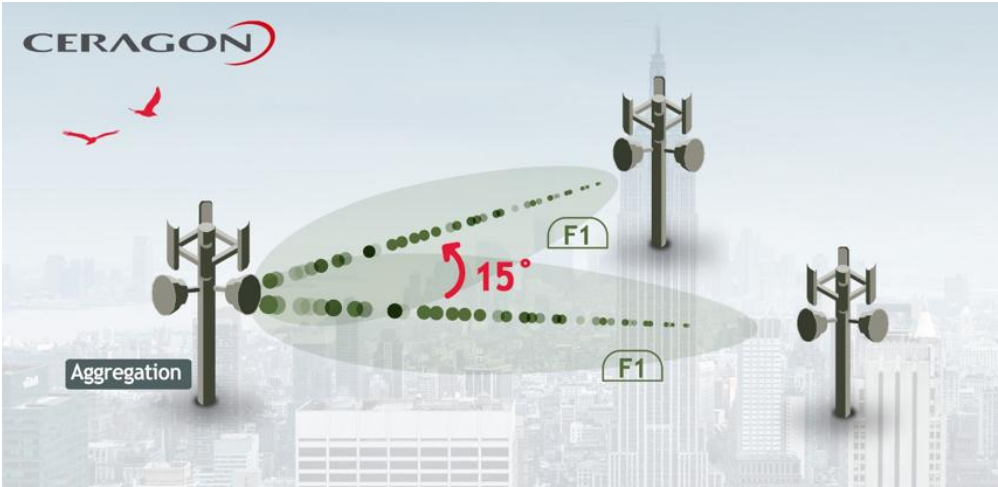


*Figure 4: $15^{o}$ Angular separation and frequency reuse*

The following diagram illustrates the effect that Advanced Frequency Reuse has on interlink interference (in this case, for Class-3 and Class-4 antennas, at 14-20GHz).

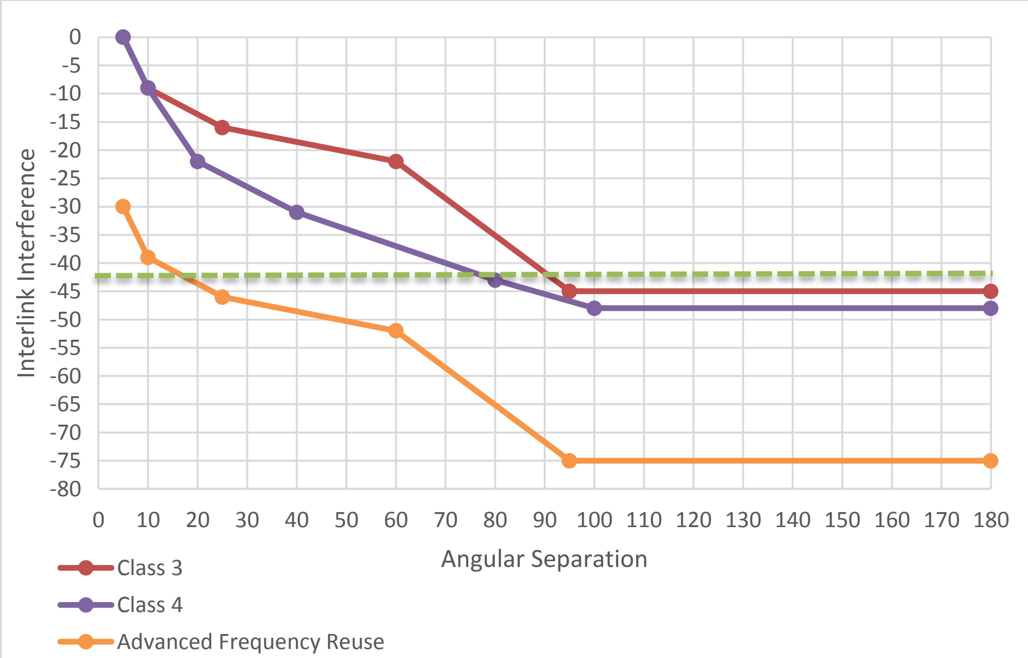


*Figure 5: Advanced Frequency Reuse gain*

The green, dashed line indicates the threshold of acceptable interlink interference (assuming a ~20dB fade margin and no XPIC). We can see that with Class-3 and Class-4 antennas, the permissible angular separation is high (70-90 degrees). The separation required by Advanced Frequency Reuse enables much lower angular separation.

With Advanced Frequency Reuse, Operators can densify their networks, deploying the additional backhaul links over the same frequency. They can also widen their channels in many cases since the widened channels can be used again and again in close proximity without concern for interference.

In the schematic below, we see four frequencies in use before applying Advanced Frequency Reuse.

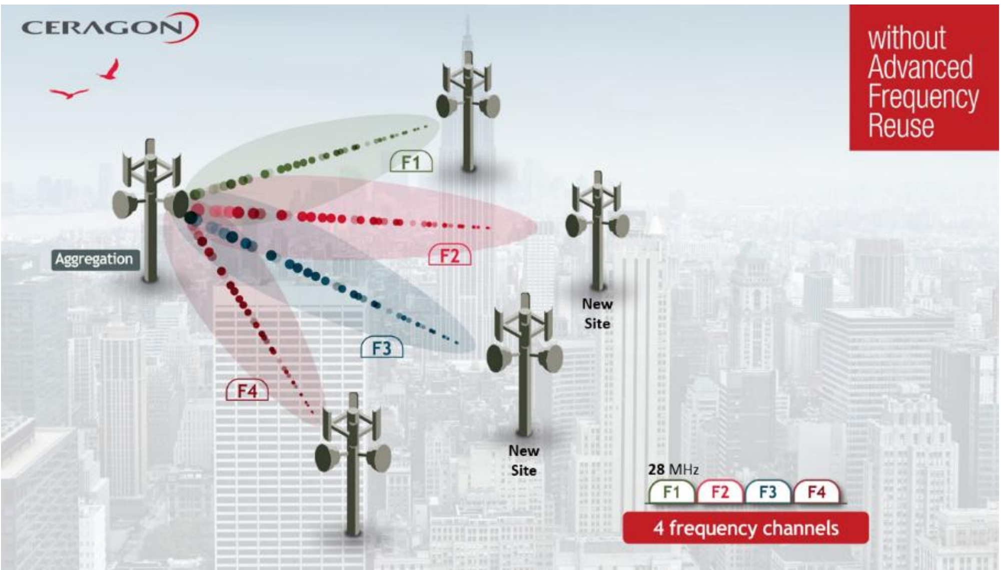


*Figure 6: Frequency planning without Advanced Frequency Reuse*

Advanced Frequency Reuse eliminates two of the frequencies while maintaining capacity.

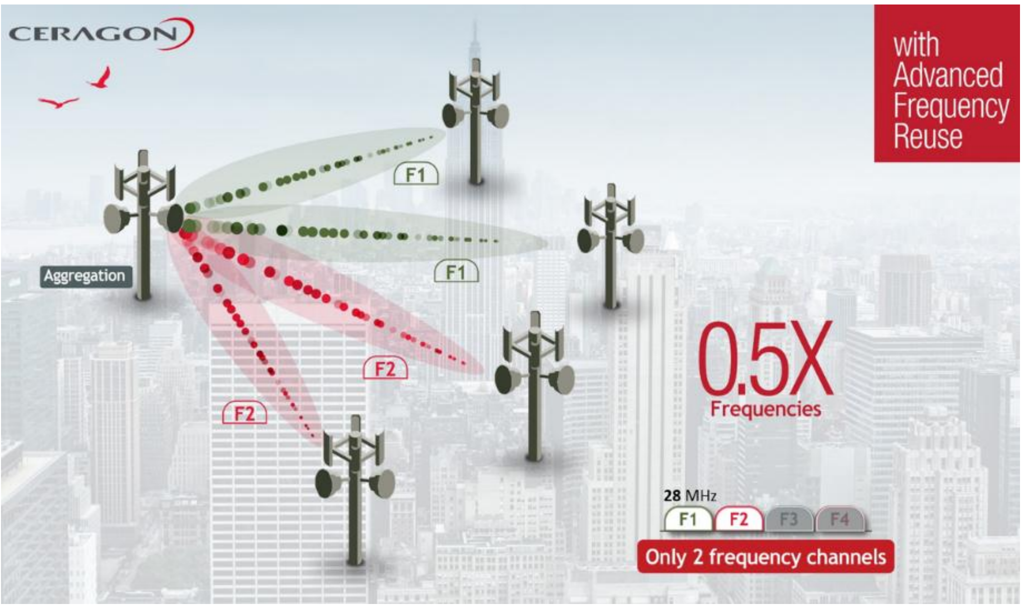


*Figure 7: Frequency planning with Advanced Frequency Reuse – same capacity, fewer frequencies*

With all four frequencies in use, Advanced Frequency Reuse doubles the capacity. This is particularly beneficial for Operators who have frequency-block allocations.

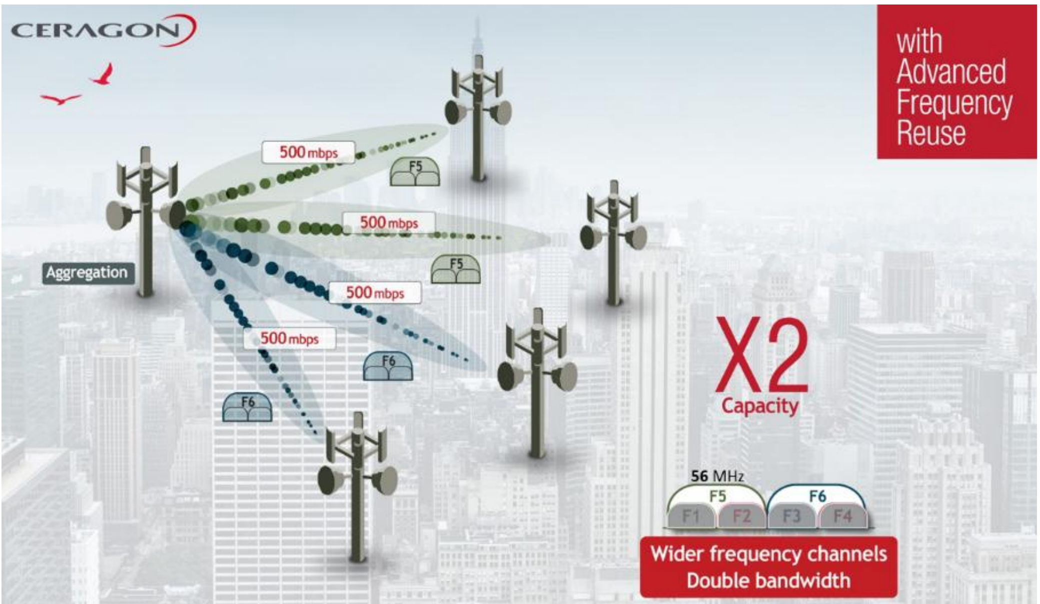


*Figure 8: Frequency planning with Advanced Frequency Reuse – double capacity*

## Summary of the Benefits of Advanced Frequency Reuse

Building on Ceragon's unique multi-core technology, Advanced Frequency Reuse bestows numerous benefits on wireless backhaul networks, keeping them at the forefront of cost-effective solutions to the problem of coping with increasing demand for capacity.

Advanced Frequency Reuse:

- Cuts interference between adjacent channels enabling far great network densification without requiring new frequencies
- Allows use of wider channels in closer proximity
- Doubles capacity per frequency channel (e.g., using 1024 QAM over two links of 28MHz channels, capacity can be doubled from 500Mbps to 1Gbps)
- Reduces the number of frequencies required to achieve a given high capacity
- Eliminates the need for expensive Class-4 antennas
- Maintains excellent quality of experience over cost-effective wireless technology
- Runs on today's FibeAir IP-20 platform
- Is implementable at the click of a mouse and does not require swapping of equipment in the field nor any truck rolls

## Conclusion

Ceragon's solutions deliver optimized wireless backhaul networks. Based on Ceragon's unique multi-core technology, Advanced Frequency Reuse enables Network Operators to get significantly more capacity of out their existing wireless backhaul frequency channels even as networks become denser. Advanced Frequency Reuse is the latest innovation that allows Operators to future-proof their wireless networks while they avoid the expenses, complexities, and delays of alternate solutions.

## About Ceragon

Ceragon Networks Ltd. (NASDAQ: CRNT) is the #1 wireless backhaul specialist. We provide innovative, flexible and cost-effective wireless backhaul and fronthaul solutions that enable mobile operators and other wired/wireless service providers to deliver 2G/3G, 4G/LTE and other broadband services to their subscribers. Ceragon's high-capacity solutions use microwave technology to transfer voice and data traffic while maximizing bandwidth efficiency to deliver more capacity over longer distances under any deployment scenario. Based on our extensive global experience, Ceragon delivers turnkey solutions that support service-provider profitability at every stage of the network lifecycle enabling faster time to revenue, cost-effective operation and simple migration to all-IP networks. As the demand for data drives the ever-expanding need for capacity, Ceragon is committed to serving the market with unmatched technology and innovation, ensuring effective solutions for the evolving needs of the marketplace. Our solutions are deployed by more than 430 service providers in over 130 countries.