OLTRE GFAST... LA PAROLA AD ADTRAN...

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G.fast and FTTdp offer service providers solid footing on which to deliver affordable, ultra-high-speed broadband access to many more people than fiber alone. In the first years of piloting G.fast proved to be the right technology to provide access to many more customers than pure FTTH would reach and keep up with demand for increasing speeds for years to come.

Introduction

With the advent of Google Fiber, AT&T LightGig, and CenturyLink's drive for FTTP (*Fiber To The Premises*), as well as other similar offerings for the residential market, there is a growing trend of delivering Gigabit services to subscribers all over the world, or perhaps more correctly, delivering services over Gigabit links to subscribers.
The thought of a fiber to every subscriber is compelling, and indeed may be the long-term goal, but how does that play out 'in the trenches' where we have to lay fiber through private properties, gardens and fences, and deal with easements, building owners and local governments? In reality, there are many circumstances where it is economically and logistically impractical to run fiber all the way to the subscriber, and we would instead prefer to use where possible, the existing copper assets.
The key to being able to provide services that approach the 1 Gbps bandwidth using existing home, apartment and other infrastructure wiring is short distances and advanced technologies. One of those advanced technologies is G.fast: it relies on a fiber connection to a neighborhood distribution point and uses copper wiring from the drop point to the customer premise.
It aims to offer speeds approaching those of Fiber-To-The-Home – up to 1Gpbs – without requiring the same level of capital investment and simplifying the access and installation in the customers' homes.
This article describes the evolution of G.fast technology - from the standardisation planning to the value brought to the market by the technology, It will also explore ADTRAN's activities with TIM on the technology. Further, it highlights how this new technology could allow operators to start thinking about a new management and central office architecture with considerations that open up to a new future.

G.fast technology today and tomorrow

The concept of a reverse-powered FTTdp (*Fiber-To-The-distribution point*) unit was first introduced to the industry by ADTRAN at Broadband World Forum in 2010. From this industry-first introduction of concept grew the G.fast standard that is now serving customers with the fastest broadband ever commercially delivered over telephony-grade copper.
G.fast is a DSL (*Digital Subscriber Line*) standard for local loops up to around 500 m. Formal standardization is being worked in ITU-T, with the first set of specifications ap-

proved in April 2014 (G.9700) and December 2014 (G.9701). This first version of G.fast specifies 106MHz profiles; wider spectrum profiles (up to 212 MHz) are planned to be included in a future Amendment 3. In G.fast, data is modulated using discrete multi-tone (DMT) modulation with originally up to 12 bit per DMT frequency carrier; Amendment 2 of the standard will extend this to 14 bit per carrier besides allowing for higher transmit power (up to 8dBm instead of 4dBm) and a lower noise floor. Use of Vectoring to deal with crosstalk between multiple pairs in a single cable is mandatory in G.fast over twisted pair copper. The first version of G.fast specifies an improved version of the linear precoding scheme from ITU-T G.993.5 G.vector. Non-linear precoding is under discussion for the future Amendment 3 in order to cope with the envisioned spectrum increase.

Up to 2012, G.fast was generally considered being a niche solution for deployment in limited FTTB (*Fiber-To-The-Building*) or FTTdp applications, only ever used where FTTH was too difficult. However, thanks to unprecedented demand to perform early trials with the technology, early adopters quickly learned that these assumptions were simply wrong. Due to the greater than expected performance of G.fast over increasingly longer distances, this technology is now being targeted for deployment in significantly more applications than originally planned.

Innovative operators like BT (*British Telecom*) began to realize that G.fast had a far greater potential, particularly on longer loops than previously anticipated. Working with the vendor community and the standards bodies, BT quickly recognized the potential of the lowly, pole mounted, distribution point unit, which had been demonstrated in their labs years earlier, and how with adaptation, the G.fast technology that evolved from it, could provide the missing ingredient needed to fast track the UK into the exclusive club of ultrafast nations. BT is so confident in the ability of G.fast to outperform other technologies on longer loops, that it has announced plans to deploy G.fast from existing cabinet locations at distances of up to 350 meters. This will provide it with an unbeatable time to market and a service speed that will leave competing technologies falling behind. Other operators with similar copper network topologies are closely following BT's ongoing field trial and are seriously planning for similar deployment models.

Further standards evolution is seeing the unleashing of higher G.fast frequencies, with double the spectrum (212 Mhz) being unlocked in Amendment 3. This latest amendment will see the introduction of a critical benefit, permitting operators to deliver a Gigabit of dedicated broadband capacity over a single copper pair. This is four times the original 100 meter performance target outlined by the G.fast standards body in 2013.

ADTRAN, working with some of its larger U.S. based customers, has continued to innovate with G.fast. Recognizing how it had surpassed every performance expectation over twisted copper pairs, ADTRAN knew that on coax cables with greater high frequency characteristics, G.fast could perform even better. This will permit delivery of G.fast over even greater distances, making it ideal for Gigabit service delivery in large MDU (*Multi-Dwelling Unit*) environments, where coax cables are often present. Stretching things further, G.fast DTA (*Dynamic Time Allocation*), presented to the ITU-T for standardization just recently, will permit real-time adjustment of the G.fast upstream and downstream transmission time allocations, providing users with symmetric-like experiences, ultimately facilitating Gigabit upload and download on the link.

On the silicon side of things, while the first generation of G.fast chipsets has proven to support units of typically 8 to 16 ports running the 106MHz profile, the upcoming second generation will support much higher port density units, up to 48 and 96 ports, as inevitably demanded by deployment scenarios on longer loops from cabinets or in large MDUs. In addition, these chipsets will also support the power boost and other improvements specified in Amendment 2 to push performance on longer loops, as well as the 212 MHz profile of Amendment 3, which will strongly increase the

performance on short loops. With this second generation silicon, ADTRAN will be able to significantly augment its extensive G.fast toolbox to provide operators with the products they need for their broad range of network scenarios. Samples of second generation chipsets are already available today and production quality silicon is expected in mid-2017.

Due to its focus on access technologies, ADTRAN believes there is no foreseeable limit on further squeezing performance out of copper and coax loops. Amendment 4 of the G.fast standard is intended to formalize bonding of G.fast lines, for which first pre-standard implementations already exist today. Both silicon as well as system vendors are experimenting with further extending the spectrum to 424 MHz and (far) beyond, reaching impressive bandwidth in the labs today. Other research is considering the use of full-duplex mode with built-in echo cancellation instead of Time Division Multiplexing. All these are of particular interest for coax scenarios where crosstalk and attenuation are far less of an issue than on twisted pair copper. The ability for G.fast to coexist with Satellite TV signals on the same COAXIAL cable, presents new opportunities for FTTB or Millimeter Wave Licensed Radio backhauled buildings, to deliver Gigabit broadband services.

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Current planning for G.fast standard amendments

ITU standard	Status	Frequency spectrum	Max Bits per carriers	Max agg. Transmit power
G.09701 specification	Approved	2-106 MHz	12	4 dBm
Amendment 1 Test parameters and low power modes	Approved	2-106 MHz	12	4 dBm
Amendment 2 New 106 MHz profiles with 8dBm max Transmit power and increased bit loading	Consented, approval process ongoing	2-106 MHz	14	8 dBm
Amendment 3 Operation without multi-line coordination for a crosstalk free environment incl. 212 MHz, DTA	Draft Proposal under work	2-212 MHz	14	8 dBm
Amendment 4	Not started yet	2-212 MHz	tbd	tbd

There have been huge achievements in developing the G.fast technology over the past few years, and there is still much that will be possible in the future. The pace of innovation is showing no sign of slowing down.

Alternative network architectures for G.fast deployment

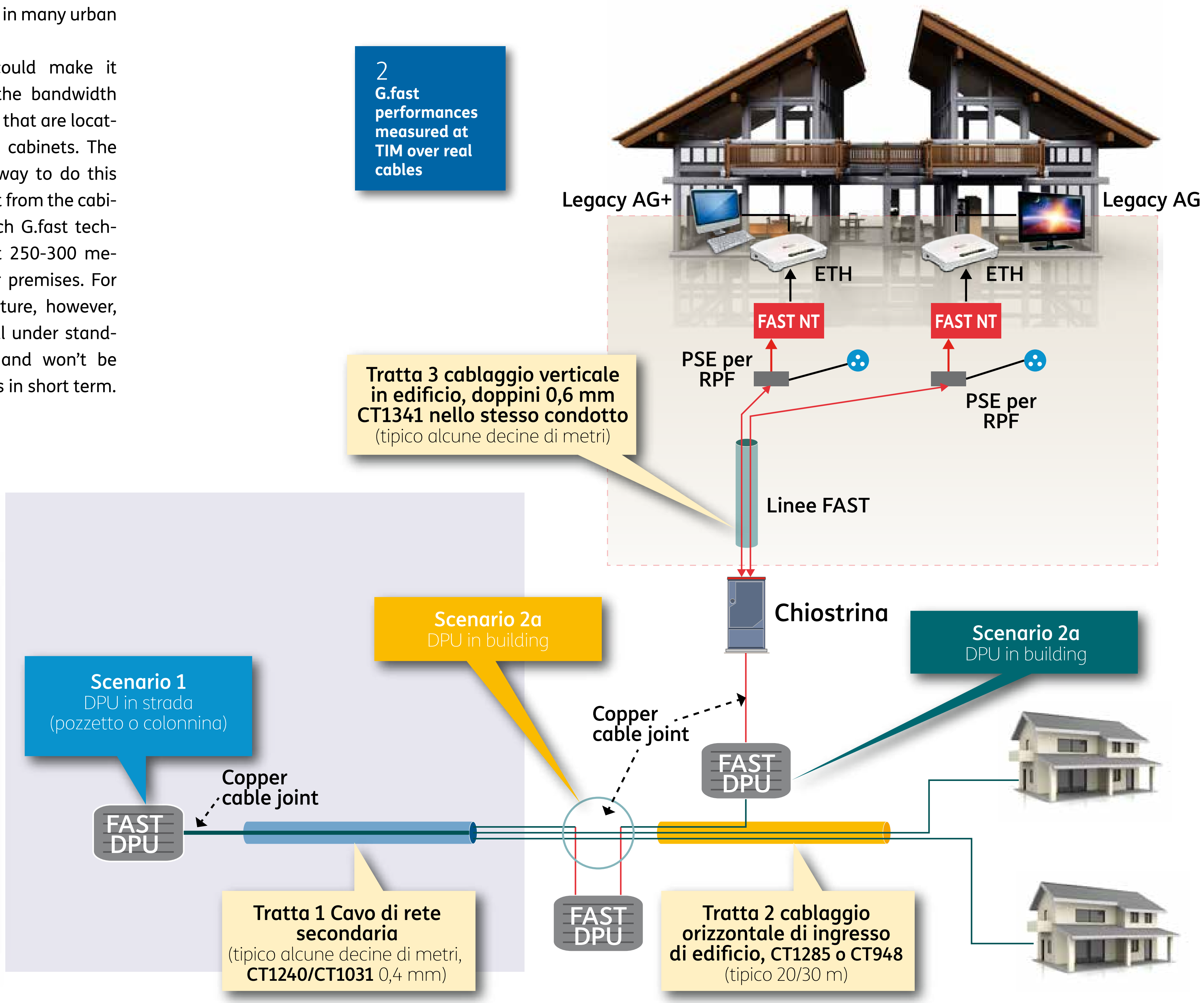
The impact of G.fast has been so significant that it has seen the technology traverse what were frequently viewed as 'religious' boundaries. G.fast deployment over COAXIAL cables, is presenting both Cable and Satellite TV providers with new alternatives for broadband delivery. Stacking up favorably against DOCSIS3.1 cost structures, G.fast has been able to secure cable industry focus, which is something that no other twisted pair technology has been successful at in the past.
Similarly, the FTTH Council for Europe, the industry lobby group that historically held an unwavering position with regards to the need for full FTTH deployment, has more recently adjusted its stance. To this end, the FTTH Council Europe has released a position paper on G.fast where it has endorsed the use of G.fast as a viable solution for FTTB applications.
It is clear that G.fast has not only proven its worth to the industry by exceeding all early expectations, but this disruptive technology is on target to become the most versatile access technology in the history of broadband access. With applications ranging from FTTCab, FTTdp, FTTB and solution densities ranging from single subscriber all the way up to 96 subscribers over broadening mediums including COAXIAL cable infrastructures, there is no doubt that G.fast will find relevance in almost every operator network in the future.

TIM and ADTRAN – bringing G.fast to Italy

In Italy, the FTTCab networks of TIM, Fastweb and Vodafone use standard VDSL2, mostly without vectoring, and claim to reach speeds of up to 100Mbps with a real average bandwidth estimated to be around 75Mbps – in many cases below that. Since Italian loop lengths are among the shortest in Europe, all operators consider G.fast technology highly appealing. They see it as a way to leverage the FTTCab deployment investments made in the last few years, which brought fiber to the street cabinets in many urban areas.
G.fast technology could make it possible to extend the bandwidth available to premises that are located near these street cabinets. The most cost effective way to do this would be to reach out from the cabinet with a 'long reach G.fast technology' over the last 250-300 meters to the customer premises. For this kind of architecture, however, the technology is still under standardisation approval and won't be available to operators in short term.

Setup cavi utilizzati per test G.fast e prestazioni aggregate misurate		
Scenario 1 Street Outdoor	**Scenario 2a** Building Outdoor	**Scenario 2b** Building Indoor
Tratta 1 (sec) CT1031 0,4 mm 40 m		
Tratta 2 (oriz) CT1285 0,6 mm 20 m	**Tratta 2 (oriz)** CT1285 0,6 mm 20 m	
Tratta 3 (vert) CT1341 0,6 mm 40m	**Tratta 3 (vert)** CT1341 0,6 mm 40m	**Tratta 3 (vert)** CT1341 0,6 mm 40m
620 Mbit/s	770 Mbit/s	815 Mbit/s

Today's G.fast technology is able to cover the last 100-150 meters of the loop in a pure FTTdp architecture, where the drop point could be a distribution box near to the building (e.g. the so-called "chiostrina"). In this scenario, a big deployment advantage is the use of the reverse powering feeding (RPF), allowing powering of the Drop Point Unit (DPU) over the copper pair via power injectors located at customer premises.
In this architecture, much higher performances than VDSL2 would be reached and vectoring issues might be reduced due to the lower number of twisted pairs in the copper cables. TIM has been working over G.fast technology in the last 2 years and measured together with ADTRAN that the reachable performances over Italian usual last 100-150 meter cables are around 700Mbps ag-



2
G.fast performances measured at TIM over real cables

3
ADTRAN G.fast installation examples at TIM

gregated line rate when vectoring is enabled and a spectrum between 2.2MHz and 106MHz is used with RPF. In case of connections below 100m length, the current performances show aggregated rates above 800Mbps under the same conditions.

Testing of G.fast technology included performance measurements under various conditions, like vectoring enabling and disabling, spectrum masking to avoid interference of other services like ADSL or VDSL2 (up to 35MHz) and RPF presence.

Now that the first chipset and device generation have reached a somewhat stable state, TIM is starting to experiment the technology in a real network environment to analyse the installation enhancements it would deliver, as well as the achievable bandwidth. Cost savings in comparison to a pure FTTH and speed of deployment are also areas being observed.

The strength of G.fast technology lies in allowing the cost effective and timely reach of customer premises without the need for drilling inside a house and laying fiber up to the home network, an activity that typical end customers would like to avoid or fully reject when it comes to a new service offering.

TIM experimentation aims at providing an understanding of the FTTx deployment models that would allow to reach the FTTH service bandwidth in those cases where laying fiber into a building is considered not possible overcoming the power supply need within buildings or on the street.

G.fast is therefore seen as a complimentary possibility to allow an extended FTTH coverage, leveraging on an existing fiber that often passes by the buildings and could be intercepted outside of those without the need for digging into the buildings.

By using G.fast technologies, the FTTH deployment that is underway in Italy could benefit in terms of coverage, number of connected homes, cost efficiency and speed of service activation.

G.fast and PMA as components of the Open Networking paradigm

As G.fast is an innovative technology deployed in new topologies, it provides operators with a once in a decade opportunity to reflect on how they implement their network, and in particular their management architecture.

The Broadband Forum has recognized that some approaches to G.fast deployment would result in the G.fast DPU being inextricably linked to the GPON OLT of the DPU provider. While some vendors will tout the merits of such an approach, ADTRAN shares the view of the Broadband Forum that operators stand to benefit the most if G.fast DPUs are independent of OLT infrastructures – removing vendor lock in and opening the way for operators to deploy the most innovative G.fast DPU solutions.

Taking this further, ADTRAN believes that as operators transition over to Next Generation broadband access solutions, like G.fast and 10G PON, they should use this opportunity to introduce open systems that not only utilize modern architectures and protocols, but also make strong use of open architectures and data models to manage the equipment. ADTRAN has already shared with the Broadband Forum G.fast DPU YANG (Yet Another Next Generation) data modeling information, which it has published. In a similar fashion, ADTRAN is working to share data modeling information for its virtualized OLT, so operators will be able to introduce Broadband Forum data model based solutions with ease.

In the context of G.fast, the Persistent Management Agent (PMA), which directly manages the G.fast DPUs, is one of the components whose deployment location can fundamentally determine how locked in an operator is to a particular vendor's G.fast architecture. ADTRAN, aligned with the Broadband Forum recommendations, believes that the optimal and most scalable implantation of PMA and PMA Aggregator (PMAA) is on the private cloud server assets of operators. By deploying in this fashion, operators can easily introduce Broadband Forum data model based G.fast DPUs from multiple vendors, under the control of their private cloud based PMAA. This approach, as opposed to the locked in approach of embedding the PMA function into an OLT, provides the maximum flexibility and scalability.

All of ADTRAN's next generation access solutions have been designed from the beginning based on open Software Defined Networking (SDN) ready architectures. Leveraging Network Configuration Protocol (NETCONF) and YANG data model foundations, these solutions can leverage the dominant open SDN controllers, like Open Network Operating System (ONOS) and OpenDayLight (ODL), while participating in leading orchestration environments like those of Blue Planet and ECOMP (Enhanced Control, Orchestration, Management & Policy).

Conclusioni

When G.fast was first introduced a couple of years ago, the most popular application proposed was for Gigabit connectivity over very short loops. In the subsequent years we have all seen this vision realised to great effect in numerous markets and scenarios, but the truth is that this approach isn't going to work for everyone or in every location.

Sub-Gigabit levels to deliver highly competitive services over longer distances have been deployed in the meantime by first-to-market service providers with the net result of delivering significantly better performance than currently available over the same infrastructure. This pioneering, responsible and pragmatic approach made many other operators all over the globe start to

think differently about their journey to FTTH.
That approach leverages the existing infrastructure - where possible - alongside innovative new technologies like G.fast, and is, in practice, infinitively preferable to telling subscribers they must tread water for the decade or more it could take an operator to deliver fully-fledged FTTH in their area.
Development of G.fast technology over the past few years has seen a plethora of achievements and deployment options and there are still significant advancements that will come in the future to significantly influence the broadband market today and tomorrow ■

Ronan Kelly

Ronan brings over 20 years' experience in the telecom industry. With first-hand experience deploying next-generation optical and copper networks, IPTV platforms, and microwave radio networks, he holds an unusually broad understanding of the challenges faced by today's operators, incumbent and competitive alike. Combining his long standing technical knowledge with his strong telecoms business understanding (operator, NREN and vendor), Ronan has assisted some of the world's largest operators maximize their value proposition and achieve market success. Ronan is dedicated to the development of ADTRAN as a global leader in the broadband access and transport arena, and continues in these efforts as we enter the exciting new era of SDN and NFV. He holds a MSc in Technology & Innovation Management and an MBA from the Dublin Institute of Technology.
Ronan was recently appointed as president of the FTTH Council Europe. As President, Ronan will take the lead on several initiatives set by the FTTH Council Europe, including supporting ongoing European FTTH rollouts and educating the market about the economic benefits delivered when communities and homes are connected to fibre.
Ronan also serves on the board of directors for The New IP Agency, an industry body that is focused on accelerating the adoption and deployment of next generation SDN and NFV based architectures and solutions by telecoms operators ■

Barbara Tonarelli

Barbara has a wealth of experience in network access solution projects for Tier 1 telecommunication operators. She has worked for over 15 years on many FTTx projects in typical fixed access telecom infrastructure markets around Europe in different sales roles from Technical Sales and Product Management to Solution and Project Management.
After a long experience on access technologies within Siemens and Nokia Siemens Networks, since 2012 Barbara joined the Sales branch of ADTRAN Italy, following activities in the Fixed Access Network innovation and Enterprise Solutions, dealing with customers and partners predominantly in Southern Europe. Barbara is part of an international team of Sales Engineers sharing experiences from several operators in the World ■

Werner Heinrich

Werner is leading ADTRAN's Portfolio Management Access & Aggregation. In this role his focus is on developing and maintaining a highly innovative and competitive product portfolio to ensure ADTRAN's leading position in next generation broadband access networks. Werner has more than 20 years' experience in the telecommunications industry in Product Management, Product Marketing and Business Development, from which he has garnered a profound understanding of the telecom market development, paired with a strong technical background in network technologies.
Werner had joined ADTRAN from Huawei, where he had been heading Product Marketing for Deutsche Telekom and its worldwide subsidiaries in the Fixed Network area. Before that he was leading the Integration and System Verification organization of the Broadband Access product line at Nokia Siemens Networks in Germany and China.
Werner has studied Computer Science at the Technical University Munich and has also earned his Ph.D. from this university ■