Cisco Digital Network Architecture

Intent-based Networking for the Enterprise

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Matthias Falkner
Simone Arena
Foreword by **Scott Harrell**

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About the Authors

Tim Szigeti, CCIE No. 9794, is a principal technical marketing engineer within the Cisco Enterprise Networking Business (ENB) team. In this role, he collaborates with customers, the field, engineering, Cisco IT, and third-party technology partners to drive the development of industry-leading network analytics solutions. In his more than 20 years with Cisco, Tim has authored/co-authored five generations of Cisco QoS Design Guides, four Cisco Press books, an IETF standard (RFC 8325), and multiple patents. Additionally, Tim has been inducted into the Cisco Distinguished Speaker Hall of Fame Elite, representing the Top 1 percent of Cisco speakers of all time.

Outside of Cisco, Tim's passion is on-track performance driving; as such, you may at times catch a glimpse of him taking corners at high speeds on the spectacular Sea-to-Sky Highway between his hometown of Vancouver and Whistler, British Columbia.

Additional information on Tim can be found on the Cisco Innovators website in the feature story "Cisco Innovators: Tim Szigeti," at https://newsroom.cisco.com/feature-content?type=webcontent&articleId=1845902.

Dave Zacks is a distinguished technical marketing engineer within the Cisco ENB team, focused on network architectures and fabrics, network hardware and ASIC design, switching, wireless, and the many and diverse technologies under the enterprise networking umbrella. Dave is based in Vancouver, Canada, and has been with Cisco for 19 years. Prior to his employment with Cisco, Dave traces his roots in computing to 1979, and has been involved in the datacomm and networking industry since 1985.

Dave is a Cisco Live Distinguished Speaker, having scored in the top 10 percent of all speakers at Cisco Live events worldwide as rated by the attendees. In addition, Dave is recognized as one of only a handful of such speakers to earn the Cisco Live Distinguished Speaker Elite designation, an honor awarded to speakers who have achieved Cisco Live Distinguished Speaker status ten times or more (Dave's total is currently 15).

In addition to his abiding focus on data communications, Dave maintains a deep and broad interest in many additional topic areas, including (but not limited to) particle and quantum physics, astrophysics, biology, genetics, chemistry, history, mathematics, cryptology, and many other topics. Dave has a special passion for rocketry, aeronautics, space travel, and advanced aircraft and spacecraft design, engineering, and operation.

Additional background on Dave can be reviewed on the Cisco Innovators website in the feature story "Cisco Innovators: Dave Zacks," at https://newsroom.cisco.com/feature-content?type=webcontent&articleId=1851941.

Dr. Matthias Falkner is a distinguished technical marketing engineer within the Cisco ENB team. He currently focuses on the evolution of enterprise and service provider network architectures, and in particular on end-to-end architecture solutions involving virtualization. Matthias is currently helping to drive the Cisco automation strategy for

enterprise networks (including DNA Center). Matthias also holds responsibilities in branch virtualization and in the definition of the cloud exchange architecture. Prior to his role within ENB, Matthias was the lead TME architect for the Cisco ASR 1000 Series routers. He has also held positions in product management, and served as a product line manager for the Cisco 10000 Series routers. From 2000 to 2005, Matthias was a consulting systems engineer in the Deutsche Telekom account team with Cisco Germany. Matthias holds a PhD in Systems and Computer engineering from Carleton University, Canada, and an MSc in Operations Research & Information Systems from the London School of Economics and Political Science, UK. His technical interests are in the area of performance characterization of virtualized networks, high availability, and service chaining.

Simone Arena is a principal technical marketing engineer (TME) within the Cisco ENB team and is primarily focused on enterprise network architecture and on all things related to wireless and mobility. Simone is based in Italy and is a Cisco veteran, having joined Cisco in 1999. Throughout the years, Simone has covered multiple roles at Cisco, starting as a software engineer working with Catalyst switching platforms, to consulting system engineer in the field, to TME within different teams (Enterprise Solution Engineering, Wireless Business Unit, and now ENB).

Today Simone is the lead TME architect for DNA Wireless, and his time is split between helping customers and partners design the best solution that fits their needs and engineering and product management, trying to evolve and improve the products and solutions.

Simone is a Distinguished Speaker at Cisco Live and has spoken at Cisco Live events all over the world for several years. He consistently is rated as an excellent speaker by attendees for his deep technical knowledge and ability to impart this information in a meaningful way.

Besides wireless, Simone has two passions: his two daughters, Viola and Anita, and his hometown soccer team, Fiorentina.

In his spare time Simone enjoys listening to music, especially through his new tube amplifier (simply awesome!).

More information on Simone can be found on the Cisco Innovators website in the feature story “Cisco Innovators: Simone Arena,” at https://newsroom.cisco.com/feature-content?type=webcontent&articleId=1849095

About the Technical Reviewers

Roland Saville is a technical leader within the Cisco ENB team, focused on developing best-practice design guidance for enterprise network deployments. He has more than 24 years of experience at Cisco as a systems engineer, product manager, consulting systems engineer, technical marketing engineer, technical leader, and architect. During that time, he has focused on a wide range of technology areas including routing, LAN switching, integration of voice and video onto network infrastructures, VoIP, network security, WLAN networking, RFID, energy management, Cisco TelePresence, Quality of Service (QoS), BYOD, Wi-Fi location, Cisco Connected Mobile Experiences (CMX), Software Defined Networking (SDN), Cisco APIC-EM, Cisco DNA, and cloud computing. He has also spent time focusing on the retail market segment. Prior to working at Cisco, Roland was a communications analyst for the Chevron Corporation. Roland holds a Bachelor of Science degree in Electrical Engineering from the University of Idaho and a Master of Business Administration (MBA) degree from Santa Clara University. He co-authored the book *Cisco TelePresence Fundamentals*, is a member of the IEEE, and has co-authored 13 U.S. patents.

Ramses Smeyers has been part of Cisco Technical Services since 2005 and currently works in the Solutions Support TAC organization as a principal engineer. Within this role he supports Cisco customers to implement and manage datacenter and campus solutions, with a focus on network automation and orchestration products. On a continual basis he creates training presentations and delivers them to Cisco technical teams across the world. He also takes a leading role on emerging technologies such as Cisco DNA, ACI, OpenStack, Ansible, and Docker.

For years Ramses has been a “customer” himself and hence perfectly understands how customers think and how to communicate with them. In his DNA, however, he’s a geek, and that’s the language he speaks to engineers. Ramses is very proficient in explaining complex messages to a variety of audiences and is a seasoned speaker at public events such as Cisco Live and Cisco PVT.

Dedications

Tim Szigeti:

To my family:

Senna, my pride: Has it really been nine years since you were born (and since I first dedicated a book to you)? I can hardly believe it! Every day you amaze, astonish, and inspire me with your inventiveness, resourcefulness, and creativity, whether you're designing cars of the future, building amazing structures from any type of construction material, or figuring out how to translate collecting chestnuts into a lucrative business venture. I don't know yet whether you will be an architect, an engineer, a scientist, a business magnate, or a full-time volunteer; but I do know that whatever you choose, you will be phenomenally successful at it! Always remember: the greatest rewards and satisfaction and joy come from serving others, and as such, may you ever be generous of your knowledge, your talents, and of yourself. Also may you ever be courageous, choosing the right path, even when an easier one is presented to you. And finally, may you ever be humble, bearing in mind that we can learn from every single person we meet.

Isla, my joy: Has it really been five years since you were born (and since I first dedicated a book to you)? I can hardly believe you're beginning *senior* kindergarten this year! What a lovely, intelligent, kind, and delightful young lady you're turning out to be! It's true, you still have me tightly wrapped around your little finger, but I don't mind; no, not at all. I wonder too what you will be when you grow up. Will you be a veterinarian? A dentist? A ballerina? An artist? An equestrian? A volunteer? I'm very excited to find out. I love that no matter what you do, you put your best and your all into your endeavors. When trying new things, remember to be patient, positive, and persistent: if things don't go quite right on the first try, dust yourself off, try to learn from what went wrong, and then give it another go. And another. And another…until you achieve your goal. I know you can do *anything* you set yourself to!

Lella, my love: Has it really been 19 years since we were married (and 14 since I first dedicated a book to you)? It's only when I stop and count the years that I begin to feel old; otherwise I still feel like the goofy nerd that you married a long, long time ago. For richer or for poorer, in sickness and in health, I consider myself blessed to have you beside me through our life journey. You're a true complement. You make me a better person, husband, and father. Without you, I'd be completely lost; with you, I just lose my keys, my socks, my patience, and sometimes my mind! But, you always manage to help me find everything that really matters. For this, and for a million other reasons, I love you forever.

Dave Zacks:

It is not often that you see a fundamentally new approach to network design and deployment begin to emerge and take hold. In a career, you may only get to see such a transition once or twice. It has been my privilege to be involved in just such an exciting journey with Cisco around the Digital Network Architecture—and my further privilege to work with a team of outstanding individuals as this transition takes place.

I dedicate this book to the multitude of people with whom I have shared this quest, and to the many friends I have made along the way.

Tim, Matt, and Simone—it has been a privilege to write this book with you, and to count you as my friends as well as co-workers.

Onward and upward! The adventure has really only just begun.

And for a bit of fun:

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…And to everyone else, I hope you really enjoy this book!

Matthias Falkner:

More than three years ago Cisco embarked on a new era in enterprise networking by developing Cisco Digital Network Architecture. For many of us at Cisco—and probably for many of you networking geeks—this implied once again a completely new vocabulary of acronyms: DNA, ENFV, SDA, SDW, FB, FC, FE, NFVIS, VNF, LISP, VXLAN, VNID, PXGrid, ISE, etc. My family and friends were once again completely flabbergasted. I had just barely gotten over traditional networking acronyms (ATM and BGP took a few years) with them, and I now started to talk about DNA and all of its concepts with a renewed passion and excitement, completely confusing my non-networking audience in the process once again.

So I would like to dedicate this book to my wonderful wife Julia, my fantastic kids Amy, Caroline, Benjamin, and Christopher, my parents Renate and Kurt, as well as my extended family who had to endure this whole new wave of acronyms. Thank you for giving me the time and patience to contribute to this book with my awe-inspiring co-authors, Tim, Dave, and Simone. I could not have done this without all of you!

Simone Arena:

My favorite artist and rock legend Bruce Springsteen sings in the 1984 song "No Surrender": *We learned more from a three-minute record than we ever learned in school.*

It's the passion, the real-world experiences, the new perspective on things that a song can communicate that strikes the listener. Well, we have tried hard to put the same ingredients into this book, so I really hope you will enjoy it.

I would like to dedicate this book, and all the effort that went into it, to my whole family. I have a wonderful big Italian family, so I cannot name them all; but I do want to mention my wife Giulia, my two princesses Viola and Anita, my mom Laura, and my father Paolo (I am sure he will be reading the book from up there). They are my strength and inspiration.

A special thank you, from the bottom of my heart, goes to my wife Giulia because she simply knows how to deal with me, she has the right attitude and always the right word for me, at the right time…so that I never give up…"no retreat, baby, no surrender…"

Acknowledgments

Tim Szigeti:

First, I'd like to thank all the readers of our books, papers, design guides, and other collateral that we've collectively produced over the past 20 years. There is nothing more rewarding than when our readers close the feedback loop by sharing their first-hand stories of how they used our content to successfully deploy technology solutions to solve their business problems. These success stories fuel us to keep innovating, making the next generation of solutions even better, and when they are, we evangelize the latest and greatest of these all around the world, and finally, we put ink to paper and write another one of these books. It is your feedback that drives our passion to go through this process again and again, taking on greater challenges each time. So thank you!

I'd also like to thank the thousands of attendees at our collective Cisco Live sessions (likely tens of thousands by now). Even when we present brand new content for the first time, we see many familiar faces in the audience. We thank you for your trust and will continually strive to prove ourselves worthy of it. I was truly surprised at how many of you have already pre-ordered this book! Your willingness to join us on a journey over new ground is very humbling and deeply appreciated.

I'd like to start off my acknowledgments of individuals by thanking Rob Soderbery and Jeff Reed for launching Cisco's Enterprise Networking Business team on our digital networking journey. This represented a brand new direction and a major paradigm shift in enterprise networking. Nonetheless, you clearly articulated your vision and the broad strokes of the architecture, and then trusted your team to fill in the details. Thank you for your bold leadership.

Many thanks to Scott Harrell, Sachin Gupta, and Ravi Chandrasekaran for accepting the DNA torch and holding it high by driving the vision all the way to shipping reality. The products you launched marked milestones in the networking industry, including the UADP ASIC (the industry's first programmable ASIC), the Catalyst 9000 Series (the fastest ramping switch of all time), and DNA Center (the industry's first automation and analytics platform). It's no small feat to make dreams come true.

Thank you Ronnie Ray and Ramit Kanda for your leadership of the DNA Center and DNA Assurance teams; also thank you both for your support on this project.

Thanks too to Mark Montanez, both for your team leadership and your technical leadership. You kept us focused on the big picture, all the while dividing and conquering the many parts that had to come together to make DNA real. You played a multilevel game of chess throughout this entire process and showed us how it was done. Your example, encouragement, and guidance truly made all of us (Dave, Matt, Simone, and me) more effective in our roles as architects and engineers. Thank you too for being the catalyst for this book project; we never would have got it off the ground without your endorsement and support. Thank you, my friend!

Jason Frazier also deserves significant thanks, as he's arguably the world's leading hands-on expert of DNA. Thank you, Jason, for all the pioneering groundwork you did in your

labs, piecing it all together and making everything work. Your brilliance, tirelessness, and sheer tenacity are the stuff of legends!

Thanks go out to Peter Jones, our resident expert in all things Doppler (i.e., UADP ASIC) and Cisco Multigigabit technology. Thank you, Peter, for taking me on a deep dive of the many layers of technical depth to be found in your ASIC by expertly navigating and summarizing multiple engineering documents (each between 10,000 and 19,250 pages in length), all without letting me drown.

Similar thanks go out to Michael Fingleton for taking me deep into the QFP ASIC, patiently breaking it apart and putting it back together again so that I could understand its inner workings.

Thank you, Jerome Henry, for always being available to share your immense knowledge, talents, and insights into wireless technologies, as well as many other related and even unrelated fields, such as advanced mathematics and statistics theories. You never hesitate to help, no matter what the ask, and you always deliver the highest quality of work. You're a true scholar and a true friend!

Thanks too to Tzahi Peleg, for always being willing to dig deep and go the extra mile to do the right things for DNA Center and Application Policy, in particular. Thanks, Tzahi, for sharing all your knowledge and passion with me. And thanks as always for tearing yourself away from the all-night discos in Tel Aviv to answer my many questions during Pacific Standard Time daytime meetings!

And thank you Guy Keinan for your talent and passion in making NBAR2 and SD-AVC the industry standard for application recognition technologies, and for taking the time to fully explain the inner workings of these to me in depth.

I'd like to also thank Michael Kopcsak and his team for challenging our status quo by helping us all to embrace design thinking philosophy and driving this into every product within Cisco Digital Network Architecture. Thank you too, Michael, for your contributions and permissions in the "Designing for Humans" chapter of this book.

Thank you, Zeus Kerravala, for your excellent and timely market and technical research, and for kindly granting us permissions for these to be incorporated into the text of this book. These clearly and specifically articulate the business value of DNA solutions.

I'd also like to thank the many members of the Cisco Press team, beginning with our executive editor Brett Bartow.

Brett: You gave us the opportunity to write this book back *before anyone had even heard of Cisco DNA*, and then you demonstrated the patience of Job in waiting for us to complete this work. Each of us has spent nearly 20 years working at Cisco, and were always used to working long and hard, but the past two years brought an unprecedented intensity to our "day jobs" that often resulted in pushing this extra-curricular effort to the backburner. Yet, you always brought us back to task and gave us whatever was needed to complete this project. Thank you for your unfaltering support in seeing this project through.

Thank you, Marianne Bartow, for doing the heavy lifting in editing and in the coordination of this entire process. You worked with us every step of the way, effortlessly solving big problems and small whenever we encountered them. We wish to express our appreciation for your efforts on our behalf and the outstanding unity and cohesion you brought to our work.

Thank you too, Tonya Simpson, for putting on the finishing touches by polishing up our content during the production phase. And thanks always to Cindy Teeters for all your administrative support during this entire project.

Next, I'd like to extend thanks to our technical reviewers Roland Saville and Ramses Smeyers.

Roland: You remain my favorite "philosopher engineer," as you can always identify the corner cases where any design recommendation breaks down and falls apart. Your technical knowledge, thoroughness, and attention to detail are second to none. I truly appreciate your comments and technical feedback. I don't even know how many books or papers you have reviewed over the years on my behalf, but I do know that I'd never write *anything* without asking for your review and input. It's not until content stands up to your technical scrutiny that I even dare to consider it good. Thank you!

Thank you too, Ramses, for coming into this project on short notice and diving right in and tackling the technical review of this extensive and diverse work.

Finally, I owe a huge debt of gratitude to my co-authors:

Thank you, Scott Harrell, for being willing to carve time out from your ultra-busy schedule of running a $20B business to write a foreword to this book! We're all very excited to see you putting your foot to the floor with DNA and the customer/market response from doing so. Thanks, Scott!

Many thanks and a shout-out to Kevin Kuhls for contributing your chapter on device programmability. This is an area that none of us has expertise in, despite listening to you present this content within our DNA Techtorial at Cisco Live after Cisco Live. We're tremendously glad (and honestly quite relieved) to have had a master write this chapter rather than fumbling through it ourselves. Thank you for patiently and expertly elucidating these important new concepts and protocols.

Grazie mille, Simone Arena! Your knowledge, expertise, and passion are off the charts! You're always willing to help others, often taking on more than you can comfortably carry, and never letting anyone down. Your work is amazing, and considering that you're writing all of this in your second language, you put us all to shame. I'm glad that with this project now closed, you'll have more time to spend with your lovely family. Go Fiorentina!

Words begin to fail me when I describe my respect, admiration, and gratitude for Matthias Falkner. Matt, you're one of the most educated and brilliant persons I've ever had the pleasure of working with; yet, at the same time, you're also one of the nicest and most down to earth. Thank you for steadfastly seeing this project through, beginning to end, when there

were many times it would have been far easier to just let it go. It's always a true pleasure working with you and learning from you. I still want to be "Matt" when I grow up.

And my final words of thanks are for the incomparable Mr. Dave Zacks. Dave, I simply do not know how you do what you do. You're a master of virtually every subject, from networking to science to history to math to aircraft/spacecraft design to genetic engineering, etc. Your passion and pursuit of perfection in all your work is simply astounding, as is your sheer prolificacy. I remember thinking again and again: there's no way Dave is going to make this deadline, and then BAM! You send in chapter after chapter, hundreds of pages at a time, written as if off the top of your head, and all at a level of technical detail that is nothing short of astonishing! And even after chapters were sent to production, you called some back so as to make incremental changes to reflect the absolute latest status of development efforts, some of which were only a few weeks old. I cannot thank you enough for all you did on this project, Dave!

Dave Zacks:

It is always difficult to single out people for acknowledgments, since there are simply so many people that help you along the way, in big ways and small—sometimes without their ever realizing that they have helped you, or provided assistance that smoothed your path, or offered insights that helped you to reach the next level, and then strive for the one beyond that.

Tim did a great job of acknowledging not only the many individuals that we have the privilege to work with daily, but also so many of the people we have all worked with that helped in one way or another to make this book possible, and to make Cisco Digital Network Architecture real. Nevertheless, I have to double down on some of those acknowledgements, and include a few additional ones of my own as well.

First, Tim Szigeti himself. Tim helped all of us as authors create structure for our work, provided consistent and timely encouragement as the book progressed, and when necessary helped "herd the cats" to drive outcomes and deadlines. Tim is so precise, methodical, and insightful that he helps to set a strong example for all of us to follow. Thank you, Tim, from all of us as authors.

Next, to my co-authors along with Tim—Matt and Simone.

Matthias Falkner is one of the most thorough and structured individuals I know, and his insights are always a source of enlightenment in any conversation. Matt's ability to see "around" a problem always serves to provide me with an additional perspective, and his sense of humor makes him fun to work with. Matt, thank you for always being the "rock" that anchors our work to a solid foundation.

Simone Arena: Well, what can I say about Mr. Arena? Not only is Simone one of the premier wireless experts in Cisco (or anywhere else, for that matter), with an astounding depth of knowledge and a strong, focused work ethic, he is also someone I am happy to count as a good friend. As I discovered several years ago, Simone and I share a love of the music of "The Boss," Bruce Springsteen. Simone, my friend, "Talk about a dream, try

to make it real…" That's what we do every day, and I am proud to work alongside you on that journey.

And a few more folks of note:

To our Enterprise Networks leadership team – Scott Harrell, Ravi Chandrasekaran, and Sachin Gupta, as well as the various Product Managers with whom I work daily (yes, I'm looking at you, Vikram Pendharkar)—thank you for your vision, the guidance you provide, and the structures you create that allow for creative execution of the DNA vision. The future success of Cisco depends on the foundation you—and all of us as a team—are laying down. Thank you for your insights, your energy, your influence, and your direction on this critical initiative for Cisco and our customers.

I'd also like to provide a big "Thank You" to my boss, Carl Solder, who has formed up the best TME team in Cisco, and I would argue, the best in the industry! You keep us all focused, charging ahead, and pulling in the same direction – no easy task! Thanks Carl for your constant support, your vision, your insights, and the inspiring example you provide.

Mark Montanez—friend, mentor, and my long-time close partner in all things Cisco. Mark, thank you for your encouragement over the years, and the many paths we have explored together—and the future paths as yet unexplored. Mark is one of those rare people who combines deep technical insights with the ability to see the "big picture," even when that picture is still forming. I have learned so very much from you over the years, my friend. Thank you, Mark, for all we have done together, and all we will collaborate on in the future.

Peter Jones—Peter is one of those individuals with whom you never can (or will) find the "bottom" of their knowledge. An inexhaustible store of information on UADP, ASIC hardware in general, and the current and future evolution of Ethernet, Peter is also able to see the larger ways in which technology impacts people, and how people can work together to make that technology more powerful. Peter has a persistent focus on how to make things better, simpler, and faster, and a relentless drive to get technical innovations adopted in the real world. A fellow fan of exceptional sci-fi, Peter is someone I am proud to count as a good friend, and someone from whom I have learned—and continue to learn—so very much. As always, look for Peter and me as co-presenters at Cisco Live, always contending for who can deliver the maximum amount of information in the minimum amount of time. Crank up the bit rates!

Shawn Wargo—When I switched over from a direct customer-facing role in Cisco into the product development teams several years ago, Shawn was already well known to me as a technical expert in Catalyst switching, as well as someone with a strong emphasis on practicality, clarity, and completeness. What I was pleased to find over the next several years is that Shawn and I have become not only closer co-workers, but also friends, with a common preference for hard-edged industrial music as well as a common focus on ASICs, hardware, and systems. Thank you, Shawn, for all the work we have done together, and all the work that remains ahead of us as we make DNA real!

There are just so many others to acknowledge that it is impossible here—it would take a book in and of itself. The Cisco Enterprise Network Business team is chock-full of brilliant minds and great people to work with, including Darrin Miller, Victor Moreno, Jason Frazier, Jerome Henry, Steve Wood, Muhammad Imam, Jeff McLaughlin, Sehjung Hah, and so many others from whom I have learned so much, and from whom I continue to learn every day. Thank you for the work we have collaborated on. And to anyone I omitted, know that our work together every day is what makes Cisco Digital Network Architecture possible.

Matthias Falkner:

Tim almost acknowledged everyone. However, the biggest acknowledgment for this book should go to Tim! He was instrumental in making this book happen. Thanks you, Tim, for being our rock at any stage in the writing process. I always felt that I could get sound advice about writing, technology, and process from you whenever I needed it. You provided me with so many doses of energy! I want to be "Tim" when I grow up!

I would also like to extend Tim's acknowledgments above to the group of Distinguished and Principal Engineers who have helped shape Cisco Digital Network Architecture. Thank you, Mark Montanez, Victor Moreno, Darrin Miller, Jean-Marc Barozet, Steve Wood, Marco Larivera, Craig Hyps, Jerome Henry, Shawn Wargo, Jason Frazier, as well as my co-authors Tim, Dave, and Simone, for all the stimulating discussions we had on defining the Enterprise Architecture Blueprint that lay the foundation for many chapters in this book. I feel truly privileged and honored to be able to learn from you. Every minute I spend on the phone or in discussions with you I learn. Thank you for helping me grow in my role as TME!

Simone Arena:

Wow! What a journey this book has been…a journey of learning, hard work, and passion. I would have never done it without my three fellow writers: Dave, Matt, and Tim. This dedication goes first to you, my friends: you inspire me with your work and made it possible for me to complete this book.

Tim, Matt, and Dave did a great job in mentioning all the people that were instrumental for this book, and I do a "plus one" on all of them; but a special mention from me goes to the following: Mark Montanez, you started it all, so it's all your fault! Jason Frazier, because every team should have a Jason. Roland Saville and Ramses Smeyers, thanks for the great work you have done reviewing this book! Talking about inspiring people, thank you, monsieur JP Vasseur: if I know a bit about analytics and machine leaning, it is because of you.

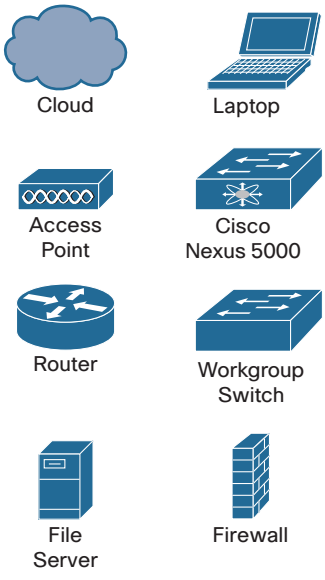
My gratitude goes also to all my colleagues at Cisco because they are the main reason for me to try and get better every day.

And finally, thank you, Carl Solder, because you believe in me and you always have my back.

Contents at a Glance

Contents

Icons Used in This Book



Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Foreword

In the last 20 years, we've seen a new kind of business arise and grow: the digital native enterprise. Companies like Salesforce, Google, Amazon, Uber, eBay, and Airbnb have leveraged digitization as a disruptive force across a variety of industries. All of these companies rely on network connectivity for their businesses to flourish. For these companies, the network is the foundation of the business.

Fly by Wire

A reliance on the flow of data isn't limited to digital native companies, however. Nearly every large business or enterprise today relies on continued connectivity among employees, partners, suppliers, customers, databases, and software services to operate.

United Airlines can't put a plane in the air if there's a network outage: Electronic systems problems, when they arise, are well-publicized reasons for system-wide ground stops. Amazon is reported to be exposed to over a million dollars a minute of losses when its servers go offline. And when a cloud service goes down, critical business functions—like sales—can go with it across industries, as some customers of Salesforce discovered in a widely publicized outage in May 2016.

For thousands of companies of all kinds, the network is the foundation.

But the network is evolving.

There are converging trends—some technological, some business-driven—that put pressure on businesses' historically static network infrastructures. For example, the growing use of multiple cloud-based services for business-critical functions disrupts typically centralized security models (while it also enables the rapid provisioning of new applications). The influx of Internet of Things (IoT) devices into the workplace upends traditional security models and creates an endpoint environment that is constantly expanding and evolving.

Connectivity is now business-critical and the availability of modern campus and branch networks must grow to reflect this new reality. The resulting new systems will be, in many ways, more complex, and they simply cannot be managed the way networks, devices, and security were run just a few years ago.

Cisco DNA Center and the New Model of Networking

At Cisco, we saw this coming. We've known for years that the network architectures we've been using—that we helped build over the last 30 years, to be honest—were not what we would need for the next generation. As end devices and applications become more dynamic, so must the network. We need to be able to instantly reconfigure every node of the network the second a decision to utilize a new application in the cloud is made, or even more quickly, based on emerging threat conditions.

For this to work, we cannot expect network operators to continue to program each network device (each router and switch) separately, nor is it realistic to expect network

managers of the near future to have to maintain complex access control lists (ACLs) and VLANs as the primary method of separating users and devices, and acting as the first line of defense for security breaches.

Telling network equipment *how* to do what we need it to do is getting less manageable by the day. Rather, we need to tell networks *what* we need them do, and then rely on them to handle the heavy lifting of configuring the equipment automatically.

This is what *intent-based networking* does, and what Cisco DNA Center is. It's the unified control system that lets IT managers set up and maintain an entire network fabric by defining rules that span network devices, and that move across the network with users as they and their devices are in motion.

Cisco DNA Center also provides a feedback loop—Assurance—that can use advanced analytics to make sure the network is doing what you intend for it to do. For security, for capacity planning, and especially for troubleshooting, this capability is invaluable, especially as enterprises' endpoint and application environments get more varied and dynamic.

Cisco DNA Center puts a coherent management interface on top of an entire network, including much of the network equipment we're using today. In other words, it's an abstraction layer on top of current systems. Network operators will be able to set up, maintain, and optimize business operations on networks without having to know every CLI on every device and be able to program every device by hand (just as business application programmers today rarely have to think about CPU-level microcode). But as we transition from traditional methods for running networks to a new, directed way to manage them, it's valuable to understand how the old and the new systems interact.

That's what I hope you get out of this book. Moving to intent-based network management is a big shift, and we know that networking experts need to learn to trust it before they learn to use it. We hope this book helps you understand the how and the why of intent-based networking in general, and Cisco DNA Center in particular, so you can take full advantage of this new capability.

The Network as Competitive Advantage

It is our sincere hope that by moving to intent-based network management, we will help network operators work more efficiently. We want you to spend less time programming multiple devices to do the same thing, less time chasing ACL configurations, and far less time troubleshooting.

With this time saved, we believe that network experts can apply their expertise to more strategic tasks. For every business running on a network (that is, nearly all of them), the people running the network can be a great lever in helping the business to run faster and be more dynamic. By focusing more on the value the network can unlock for businesses, and a little less on the minutiae of how it works, we'll be able to build more robust, more competitive, more agile, and more secure enterprises.

—Scott Harrell

SVP, Cisco and GM of Cisco's Enterprise Networking Business (ENB)

Introduction

Cisco Digital Network Architecture (DNA) represents the most fundamental change in enterprise networking in the past decade (possibly decades!).

To enable, facilitate, and accelerate the digital transformations of enterprises and to meet future business demands of networks (including multi-cloud, IoT, encrypted threats, etc.), Cisco has taken an entirely new approach to networking: intent-based networking. Thus, Cisco has re-engineered the enterprise network architecture, infrastructure, and solutions from the top down to align to this intent-based networking approach, the result of which is Cisco DNA.

Goals and Methods

The goal of this book is to introduce you to Cisco DNA, highlighting the current and future value propositions it offers to customers, the philosophy, tenets, and blueprints of the architecture, its hardware and software components, and the current solutions enabled by this architecture.

Who Should Read This Book?

This book has been written for four groups of readers:

- **Business decision makers (BDMs):** This book enables BDMs to see the impact that DNA can have on their business as a whole, to drive digital transformation and to gain competitive advantage.
- **Technical decision makers (TDM):** This book familiarizes TDMs with powerful emerging technologies and solutions that address their specific business needs.
- **Network architects:** This book provides technical details of cutting-edge technologies to network architects tasked with deploying these solutions, highlighting recommendations, interdependencies, limitations, and caveats.
- **Network operators:** This book provides guidance for network operators running DNA Center in their enterprise, showing them how to use this user-friendly interface to operate and benefit from powerful new networking solutions.

The authors of this book are principal and distinguished engineers who are leading the engineering efforts on DNA and are incredibly passionate about the work they are doing. As such, their motivation behind writing this book is their enthusiasm to share these latest and greatest breakthroughs in enterprise networking with any and all interested parties.

How This book Is Organized

This book is organized into 23 chapters in 6 parts.

Note The number of chapters in this book on Cisco DNA happens to correspond exactly to the number of chromosomes found in human DNA. As such, both happen to have 23 "chapters." This fact, however, is pure coincidence. Nonetheless, it makes for an interesting, albeit unintentional, parallel.

In Part I, "Introduction to DNA," readers are presented with business requirements, user requirements, and technical requirements of the enterprise network architecture. The five chapters in Part I are as follows:

- **Chapter 1, "Why Transform Your Business Digitally?":** The goal of this chapter is to understand the business opportunities and challenges that customers are facing in digital transformation, setting context for how Cisco DNA addresses these.
- **Chapter 2, "The Business Value of DNA":** This chapter introduces the concept of intent-based networking, and provides specific examples and data points of how Cisco DNA can reduce costs, mitigate risks, provide actionable insights, and increase business agility.
- **Chapter 3, "Designing for Humans":** This chapter serves as an intersection between business requirements and technical requirements by focusing on a third dimension of requirements: user requirements. It introduces the Design Thinking philosophy that Cisco employed in its top-down approach to DNA.
- **Chapter 4, "Introducing the Digital Network Architecture":** This chapter provides a technical introduction to Cisco DNA by outlining guiding architectural principles and tenets and introducing various components, including network infrastructure, network controllers, and network analytics platforms. (Note that the theme of the next three parts of the book are centered on these respective components.)
- **Chapter 5, "The Digital Network Architecture Blueprint":** This chapter "peels the onion" to expose the next level of architectural detail by showing how Cisco DNA components interact to connect users, devices, and applications. This chapter defines services in detail and explains concepts such as domains, scopes, and fabrics. It also offers an abstracted yet detailed blueprint to provide a framework for current and future elements of Cisco DNA.

Having introduced Cisco DNA in Part I, the next three parts are centered on key components of the architecture, specifically infrastructure, automation, and analytics. As such, Part II, "DNA Programmable Infrastructure," focuses on hardware, software, and protocol innovations within the infrastructure that provide the foundation for Cisco DNA. Part II is composed of six chapters:

- **Chapter 6, "Introduction to DNA Infrastructure":** This chapter presents evolving business needs of the network infrastructure, including the need for simplicity, continuity, and speed. Additionally, this chapter outlines how programmable hardware, flexible software, evolving protocols, and virtualization address these needs.
- **Chapter 7, "Hardware Innovations":** This chapter dives deep into hardware innovations for enterprise switching, routing, and wireless platforms. After an overview of application-specific integrated circuit (ASIC) design and production, this chapter provides in-depth details about the Cisco Unified Access Data Plane (UADP) ASIC, which represents the heart of DNA switching platforms, such as the Catalyst 9000 Series switches. A similar discussion follows on the Cisco QuantumFlow Processor (QFP) ASIC, which powers Cisco ASR routers. And finally, this chapter details wireless hardware to show how it enables new protocols, speeds, capabilities (like precision location and tracking), and analytics.
- **Chapter 8, "Software Innovations":** This chapter traces the evolution of Cisco IOS software (data plane, control plane, and management plane) and highlights the benefits of Cisco IOS XE software, in particular its cross-platform consistency, simplicity, flexibility, modularity, and support for containers for application hosting. This chapter also discusses trustworthy systems and the importance of secure infrastructure, as well as the move to controller-based networking via programmable interfaces.
- **Chapter 9, "Protocol Innovations":** This chapter outlines the evolution of networking protocols, beginning with Ethernet protocols and Power over Ethernet (PoE) and arriving at the movement toward Multigigabit Ethernet (mGig) over copper. It also provides an overview of the evolution of Layer 2 and Layer 3 protocols and next-generation networking protocols such as VXLAN, LISP, and TrustSec.
- **Chapter 10, "DNA Infrastructure—Virtualization":** This chapter complements the previous chapters by showing how the network functions enabled by hardware, software, and protocol innovations can be virtualized. Network function virtualization (NFV) enables network functions to run inside virtual machines on standard Intel x86–based hosting platforms; as such, NFV is inherently software driven. These functions can be quickly and easily deployed (even on an on-demand basis), providing network administrators flexibility, efficiency, and cost effectiveness.
- **Chapter 11, "DNA Cloud":** This chapter discusses how on-premises infrastructure can be extended to the cloud. It covers cloud service models, cloud deployment types and modes, multi-cloud challenges and solutions, and how DNA integrates with cloud-based service offerings.

Having laid a solid foundation at the infrastructure layer of the architecture, the discussion next proceeds to a higher layer of the architecture, beginning with Part III, "DNA Automation." The three chapters in this part highlight how network operations can be simplified and scaled using network controllers.

- **Chapter 12, "Introduction to DNA Automation":** This chapter explains the business reasons driving network automation, as well as the many operational benefits that can be realized by it. Also discussed are the differences between generic software-defined networking (SDN) and Cisco DNA Automation.
- **Chapter 13, "Device Programmability":** This chapter highlights the limitations of current tools used for programming—and gathering telemetry from—networks, and introduces new technologies that enable greater flexibility, efficiency, and capabilities than ever before. These technologies include the Network Configuration (NETCONF) protocol, Representational State Transfer Configuration (RESTCONF) protocol, Google Remote Procedure Call (gRPC) protocol, and Yet Another Next Generation (YANG) models for configuration and operational data.
- **Chapter 14, "DNA Automation":** This chapter discusses the importance of DNA automation as a major functional block in the architecture, drawing attention to how DNA automation goes well beyond the automatic configuration of individual network devices by allowing operators to treat their entire network as a single, cohesive, programmable system. This chapter explains how standardized network designs contribute to this objective, as well as how network functions are automated. The ongoing lifecycle management of DNA network elements is also addressed.

A key function that automation platforms provide is "talking" to the network—that is, taking the business intent expressed by the network operator, translating this into device-specific configurations, and then deploying these configurations at scale and end to end across the infrastructure. While this is an important function, it needs to be complemented by platforms that "listen" to the network, which is the key function performed by network analytics platforms, as discussed in Part IV, "DNA Analytics." Specifically, the DNA Analytics platform "closes the loop" by gathering telemetry data from the network and analyzing this data within the context of the expressed business intent so as to confirm either that the intent has indeed been delivered across the network or that it hasn't (in which case remediation actions can be triggered). Part IV is composed of three chapters:

- **Chapter 15, "Introduction to DNA Analytics":** This chapter introduces network analytics by examining the process of discovering, interpreting, and communicating meaningful information from raw network data and the business value that such actionable insights can present. Network analytics is broken down into its subcomponents, including infrastructure analytics, endpoint analytics, application analytics, user analytics, and policy analytics.
- **Chapter 16, "DNA Analytics Components":** This chapter explores the architectural components required to create an analytics solution, including instrumentation, distributed analytics, telemetry, and analytics engines. The roles and interrelationships of each component are examined, as well as how they come together to form a cohesive and comprehensive solution.
- **Chapter 17, "DNA Analytics Engines":** This chapter dives into detail on the analytics engine, highlighting how it can be used for network health monitoring, performance tuning, capacity planning, security analysis and threat prevention,

and troubleshooting. To enable these use cases, network analytics engines need to perform data transformation, aggregation, and correlation, as well as time-series analysis and network baselining (via machine learning), all of which topics are discussed in this chapter.

Part V, "DNA Solutions" (arguably the most exciting part of the book), takes the concepts, principles, and components discussed thus far and shows how these are combined into cutting-edge architectural solutions that are significantly greater than the sum of their parts. The five chapters in Part V are as follows:

- **Chapter 18, "DNA Virtualization Solutions: Enterprise Network Functions Virtualization and Secure Agile Exchange":** This chapter presents two distinct use-case solutions of enterprise network function virtualization:
  - The virtualization of branch architectures, which focuses on the Cisco Enterprise Network Compute System (ENCS) and Cisco Enterprise Network Function Virtualization Infrastructure Software (NFVIS)
  - The virtualization of policy-based connectivity to external domains for multi-cloud architectures, namely the Cisco Secure Agile Exchange (SAE) solution, which combines virtualization with policy to allow network operators to define intent-based communication policies to connect employees, partners, customers, and/or guests to applications hosted in private, virtual private, or public clouds
- **Chapter 19, "DNA Software-Defined Access":** This chapter examines one of Cisco's newest and most exciting innovations in the area of enterprise networking: Software Defined Access (SDA). SDA presents an entirely new way of building—or even of thinking about and designing—enterprise networks. SDA revolutionizes networking by decoupling the IP address logical-addressing function from policy (IP ACLs have long been the traditional method of applying policy to users, groups, and applications, resulting in the IP address becoming overloaded with meaning, leading to brittle network designs and overwhelmingly complex network policies). SDA utilizes multiple components of DNA, including automation, assurance, and integrated security capabilities to deliver significantly increased simplicity, flexibility, security, mobility, visibility, and performance to enterprise networks.
- **Chapter 20, "DNA Application Policy":** This chapter presents a first-of-its-kind solution for intent-based application networking in the enterprise. DNA provides a comprehensive architecture to monitor, manage, provision, and troubleshoot applications. Specifically, DNA infrastructure provides powerful hardware and software capabilities to support granular application recognition—of even encrypted applications—as well as flexible and detailed application treatment capabilities. In turn, DNA Application Policy automates the deployment of intent-based application policies in an end-to-end manner over both brownfield and greenfield networks. Complementing these functions, DNA also includes application assurance (which is discussed in detail in Chapter 21) to monitor, report, and remediate (when necessary) how applications are being treated across the network.

- **Chapter 21, "DNA Analytics and Assurance":** This chapter discusses the role of analytics and assurance within the enterprise network architecture and introduces the DNA Analytics platform (an industry first), as well as the unprecedentedly powerful network monitoring and troubleshooting application that it enables: DNA Assurance. Most enterprises are bogged down by network monitoring and troubleshooting operations, and are challenged to collect data, replicate issues, resolve issues in a timely manner, and free the network from being blamed (which it often is, by default). To meet these challenges, DNA Assurance uses a time-series database (similar to a TV digital video recorder) to monitor the health of clients, network devices, and applications running on enterprise networks. Thus, IT support staff are freed from having to replicate issues; all they have to do is go "back in time" to whenever an issue was manifest, and see the entire state of the network at a given moment in time, allowing them to troubleshoot the root cause of the issue. DNA Assurance also expedites the troubleshooting and remediation process by leveraging contextual correlation, machine learning, and guided remediation.
- **Chapter 22, "DNA Encrypted Traffic Analytics":** This chapter presents a solution to what was (until recently) thought to be an unsolvable problem: how to identify threats in encrypted traffic. As the majority of enterprise traffic is now encrypted, cyber attackers seek to benefit from this lack of visibility by injecting malware and ransomware into the payloads of encrypted packets. However, DNA Encrypted Traffic Analytics (ETA) presents an architectural approach that combines programmable hardware, sophisticated software, automation, analytics, and cloud-based machine learning to produce a solution that has greater than 99 percent accuracy in detecting malware in encrypted traffic (with less than 0.01 percent false positives). This chapter examines two key use cases offered by ETA: encrypted malware detection and cryptographic compliance.

DNA is the Cisco long-term strategy for enterprise networking, and represents a journey that has only just begun. In the final part (and chapter) of this book, Part 6, "DNA Evolution," the authors share some of their prognostications (bounded by confidentially and intellectual-property restrictions) of future expressions of this architecture.

- **Chapter 23, "DNA Evolution":** In this final chapter, the authors (all of whom serve as DNA architects) wanted to share some of their thoughts on how they see DNA evolving over the next few years, thus presenting a sense of where DNA is heading (without giving away strategically competitive details). Also considered is the role of the network administrator and the skill sets that will maximize value in the transitions to come.

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Chapter 1

Why Transform Your Business Digitally?

The primary goal of Cisco Digital Network Architecture (DNA) is to accelerate the digital transformation of customers' businesses. Therefore, before diving into the technologies within this architecture, it's important to understand the business opportunities and challenges that customers are facing, thus setting relevant context for how DNA addresses these.

This chapter introduces and discusses the following:

- The opportunities and threats presented by digital transformation
- How digital technologies have transformed entire industries
- Case-study examples of how digital technologies are transforming key areas of business, including:
  - Customer experiences
  - Employee experiences
  - Operations
- Digital transformation and the Internet of Things (IoT)

Opportunities and Threats

Transform or die. It's really that simple when it comes to digital business. Provide your customers new experiences, delivering them greater value, personalization, convenience and satisfaction—or your competition will. Enable your employees new workplace experiences, empowering them to collaborate effectively, and effortlessly, improving their overall productivity and job satisfaction—or your opposition will. Leverage technology to reduce costs, make informed data-driven decisions, and reallocate resources from operation to innovation—or your rivals will.

Does that sound a bit dramatic? Not according to a 2015 study[1] of 941 companies around the world in 12 different industries done by the Global Center for Digital Business Transformation, which highlighted that roughly 40 percent of today's top ten incumbents (in terms of market share) in each industry will be displaced by digital disruption within the next five years. Furthermore, the same study showed that 43 percent of companies either do not acknowledge the risk of digital disruption or have not addressed it sufficiently, with nearly a third adopting a "wait and see" attitude. The industries most under threat of digital disruption are shown in Figure 1-1.

In contrast, companies that have mastered digital technology transformations have outperformed their industry peers by 9 percent in revenue generation and 26 percent in profitability, according to the Harvard Business Review Press book *Leading Digital*.

How real is digital transformation? To answer this, let's consider some examples of entire industries that were either significantly disrupted or completely transformed by various forms of digitalization.

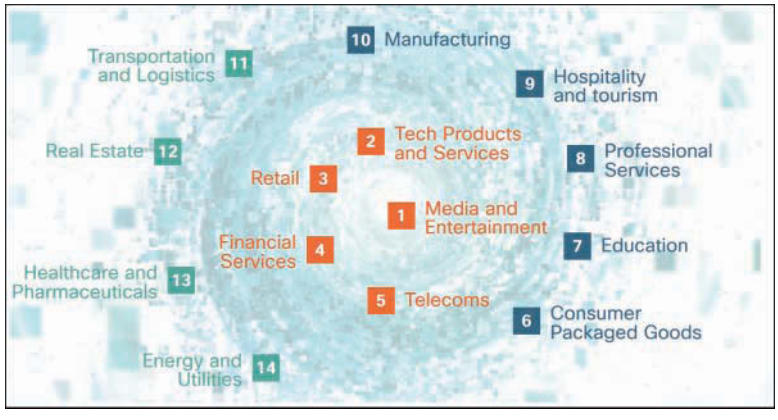

Figure 1-1 *Threat of Digital Disruption by Industry (Image Credit: Global Center for Digital Business Transformation, an IMD and Cisco Initiative https://www.imd.org/dbt/digital-business-transformation/)*

1 J. Bradley, J. Loucks, J. Macaulay, A. Noronha, and M. Wade, "Digital Vortex: How Digital Disruption Is Redefining Industries," Global Center for Digital Business Transformation, June 2015, https://www.cisco.com/c/dam/en/us/solutions/collateral/industry-solutions/digital-vortex-report.pdf.

Digitally Transforming Industries

Industries such as advertising, media and entertainment, finance, communications, transportation, and others have been radically transformed by the advent of digital technologies and processes. Incumbents that adopted "wait and see" attitudes were quickly displaced, while bold innovators grabbed market share at astonishing rates, as the following few examples demonstrate.

Digital Advertising

In 1995, Craig Newmark posed an email distribution list to friends, featuring local events in the San Francisco Bay Area. This list became a web-based service, called Craigslist, the following year and has since expanded to over 570 cities in 70 countries worldwide. As Craigslist steadily gained popularity, eventually becoming a top-100 website, it virtually single-handedly put the newspaper classified-advertising industry out of business in every city it entered, while earning itself nearly $700 million in annual revenues—all with only 50 employees!

Similarly, digital advertising for local businesses by applications like Angie's List, Yelp, and others have displaced paper-based "Yellow Pages" telephone directories, which held the monopoly for local business advertising for over 40 years.

Companies that have been slow to adapt to the shift from print advertising to digital have suffered similar fates. In sharp contrast, companies like Google, Facebook, and Baidu have embraced digital advertising and transformed themselves into industry leaders in this $187B[2] market, earning themselves $19B, $18B, and $10B (respectively) in 2016, and collectively garnishing 25 percent of the global market.

Digital Media and Entertainment

Apple complemented the release of the iPod in 2001 with its digital music iTunes Store in 2003. Within five years iTunes became the world's largest music vendor, earning over $6B per year in revenue. Concurrently, music retail stores like Virgin Megastores, HMV, Tower Records, and others closed up shop en masse.

In the video entertainment industry, scarcely a decade ago Blockbuster ruled as king, boasting 60,000 employees in over 9000 stores and nearly $6B in annual revenue. In one of the greatest instances of modern business irony, Blockbuster turned down an offer to purchase newcomer Netflix for $50M in 2000. Undaunted, Netflix transformed the video entertainment industry several times over: The first transformation digitalized the movie-selection process, enabling users to browse for movies online, rather than at a store (and the movies selected would be mailed to them on DVDs). The second, and more impactful transformation, was Netflix's digitalizing the delivery process as

2 Deepa Seetharaman, "Facebook Revenue Soars on Ad Growth," *Wall Street Journal*, April 28, 2016, http://www.wsj.com/articles/facebook-revenue-soars-on-ad-growth-1461787856.

well, enabling movies to be streamed to customers directly, anytime, anywhere, and on virtually any device. Yet another transformation saw Netflix become an original content producer, as well as distributor. The result of these digital transformations has made Netflix the world's leading Internet television network with over 125 million members in over 190 countries, earning over $11B in annual revenue. In 2018, Netflix, which was esteemed by Blockbuster as not being worth $50M, reached a market capitalization in excess of $144B.

Digital Finance

To facilitate the exploding demand of online purchases and transactions, PayPal digitalized the payment process. Sending checks and money orders through the mail seems like an artifact of the distant past now, in contrast to the flexibility, convenience, and speed of funds transferred via PayPal. Such customer benefits translate to significant bottom-line results for PayPal, who in 2017 processed over 5 billion transactions for 237 million users and earned $13B in revenue.

Digital Communications

With the advent of Voice over Internet Protocol (VoIP) technologies in the early 2000s, incumbent telecommunications providers were put under pressure to compete—which for many proved to be a new experience, having had the luxury of being geographic monopolies for decades. In the process they lost hundreds of billions of dollars. And the hemorrhaging continues. For example, a recent study estimates that the telecommunications industry will lose a further $386B between 2012 and 2018 to over-the-top (OTT) VoIP applications.[3]

In fact, a single application, WhatsApp, is threatening the short message service (SMS) market as a whole, as shown in Figure 1-2. WhatsApp provides users more flexibility and cost savings as compared to SMS, allowing users to send not only text messages, but also photos, videos, documents, and other media. And when users are connected to Wi-Fi networks, they can send and receive their messages and media for free, avoiding SMS data charges. The value of WhatsApp is recognized by many, including Facebook, which acquired it in 2014 for $19.3B. In 2016, WhatsApp surpassed 1 billion users.

Additionally, as the mobile messaging industry is becoming increasingly commoditized, regulatory changes (such as prohibiting roaming charges in certain markets) are putting even more pressure on classical business models utilized by telecom incumbents, further exacerbating their disadvantage to digital transformers, like WhatsApp.

3 Erik Heinrich, "Telecom Companies Count $386 Billion in Lost Revenue to Skype, WhatsApp, Others," *Fortune*, June 23, 2014, http://fortune.com/2014/06/23/telecom-companies-count-386-billion-in-lost-revenue-to-skype-whatsapp-others/.

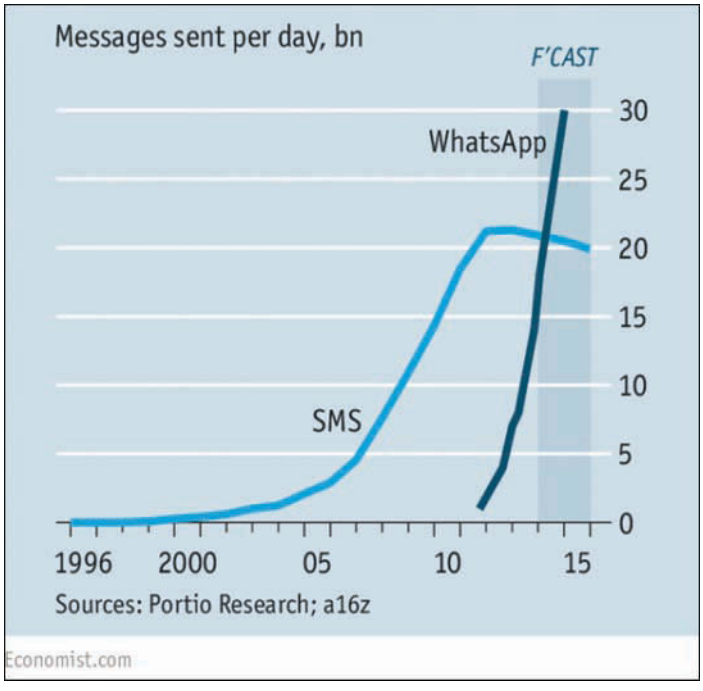

Figure 1-2 *WhatsApp Versus the SMS Industry*[4]

Digital Transportation Services

In San Francisco, New York, Chicago, and over 600 additional cities worldwide, hailing a cab is becoming a quaint memory, thanks to Uber, launched in 2011. In just a few short years, Uber completely transformed the taxi industry by leveraging digital technology. The Uber app, shown in Figure 1-3, allows customers with smartphones to submit a trip request, which is automatically sent to the nearest Uber driver, alerting the driver to the location of the customer, and vice versa. Customers know exactly how long they have to wait and can watch on a map as their driver is approaching their location. Drivers know exactly where their customers are and where they wish to go, and can receive Global Positioning System (GPS) directions to their destination. Transactions are cashless and paperless, with receipts being emailed to the customers (facilitating easier expense reporting for business travelers). Additionally, the Uber app also serves to prevent language barriers, as can often be the case when communicating with taxi drivers in foreign cities. Uber also benefits drivers, who for the most part are freelance and use their personal vehicles, saving them significant franchising fees and operating overhead commonly incurred by taxi operators. In 2017, Uber—still a private company—was valuated at nearly $70B.

4 Satoshi Kambayashi, "The Message Is the Medium," *The Economist*, March 26, 2015, https://www.economist.com/business/2015/03/26/the-message-is-the-medium.

Figure 1-3 *Uber Ride-Sharing Service*

Zipcar has had a similar impact on the traditional rental-car industry. Founded in 2000 in Boston, the car-sharing service operates 10,000 vehicles in over 500 cities in 9 countries serving over a million users. As such, Zipcar is one of the world's leading car rental networks in its own right. Members can reserve cars with Zipcar's mobile app, online, or by phone at any time—immediately or up to a year in advance. Members have automated access to Zipcars using an access card which works with the car's technology to unlock the door, where the keys are already located inside. The Zipcar mobile app also enables members to remotely honk the horn to locate their reserved Zipcar and unlock the doors (see Figure 1-4). As such, many urban residents find Zipcar to be a convenient and cost-effective alternative to buying, maintaining, and parking their own cars.

Note Avis acquired Zipcar in 2013 for $500M, providing a counter-example to Blockbuster, mentioned earlier. Specifically, Avis demonstrated foresight in adapting to digital transformation via a strategic acquisition.

Similarly, thanks to advances in digital technologies, bicycle-sharing services have exploded globally since the mid-2000s. As of June 2014, public bicycle-sharing systems were available in 712 cities, spanning 50 countries on five continents, operating approximately 806,200 bicycles at 37,500 stations. While implementations differ, bicycle-sharing companies often include wireless bike station terminals running on solar energy, radio-frequency identification (RFID) bike dock technology, and smartphone apps that locate and show the status of bike stations close to the users (see Figure 1-5). Bicycle-sharing systems aptly demonstrate the significant positive impact that digital technology can have on the environment as well as on the overall health of urban populations, by facilitating a greener and healthier transportation alternative.

Figure 1-4 *Zipcar Car-Sharing Service*

Figure 1-5 *Public Bike Sharing*

Digitally Transforming Businesses

While not every digitally transformed organization ends up reshaping its entire industry, such companies are—on average—26 percent more profitable than their industry peers, as has already been noted. This fact alone has encouraged many organizations to examine areas where they can digitally transform. Some of these key areas include

- Customer experience
- Employee experience
- Business operations

The following sections provide an overview of each of these areas, along with examples of industry leaders in each area.

Transforming the Customer Experience

Customer experience matters more than ever. And bad customer experiences can be fatal to a business.

For example, in 2011 Harris Interactive published a Customer Experience Impact Report that found that:

- 86 percent of customers will pay more for a better customer experience.
- 89 percent of consumers began doing business with a competitor following a poor customer experience (up from 68 percent in 2009).
- 79 percent of consumers who shared complaints about poor customer experience online had their complaints ignored.
- 50 percent of consumers give a brand only one week to respond to a question before they stop doing business with them.

Additionally, Forrester Research showed that a quarter of American consumers who had unsatisfactory service interactions in 2010 shared their experiences though social networks, which represented a 50 percent increase from the year before.[5]

Furthermore, an increasing number of customers are making purchasing decisions based on what their peers have to say, paying close attention to ratings, reviews, and testimonials on social-media and third-party sites and apps. As such, businesses have incentive like never before to leverage digital technology to provide superior customer service, as some of the following companies have demonstrated.

Burberry

In 2006 Burberry was lagging far behind its competitors. The high-fashion industry was growing at 12 to 13 percent per year, but Burberry was managing only 1 to 2 percent growth. Burberry's new CEO at the time, Angela Ahrendts, decided to rebrand the company and focus on a new market: millennials. As such, Burberry undertook an aggressive digital strategy to reach this new customer base. It revamped its website and included an "Art of the Trench" social-media element where anyone could post pictures of themselves in their classic Burberry coat. Burberry partnered with Twitter to broadcast live fashion shows, and likewise partnered with Google to develop advanced "lip detection technology" so that customers could send digital kisses to loved ones anywhere in the world.

5 www.forrester.com/North+American+Technologies+Customer+Experience+Online+Survey+Q4+2010+US/-/E-SUS805

Burberry also complemented its online digital presence with extensive digital technologies in its retail stores, such as giant external and internal video displays in all its stores and by arming all its sales associates with iPads. Burberry's fusion of digital and retail fashion is illustrated in Figure 1-6. Burberry even creatively combined RFID technology with its video displays, such that, for example, when a customer took a garment into a changing room to try it on, the RFID sensor recognized which garment(s) the customer was trying on and automatically signaled the video display in the changing room to begin playing a video of a fashion model wearing the same garment. This particular combination of digital technologies led to a significant increase in conversion rates to purchases. The net result of all these new digital customer experiences was the tripling of Burberry sales, as well as its share price, during Ahrendts' tenure.[6]

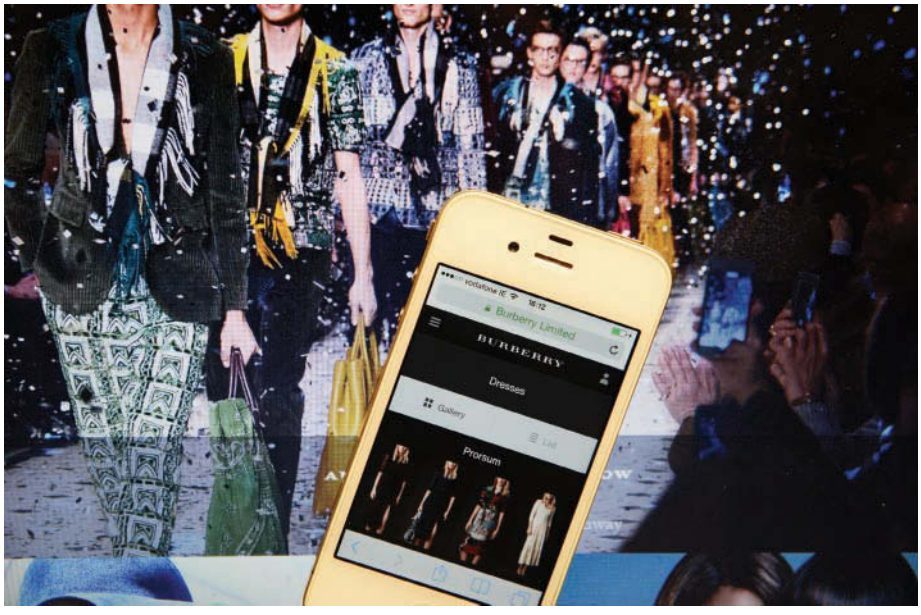

Figure 1-6 *Burberry—Fusing Digital and Physical Retail*

Starbucks

Starbucks has been well described as "a digital innovation machine."[7] It was one of the first coffee chains to recognize the value of offering its customers free Wi-Fi, along with content (delivered by partnering with the New York Times, The Economist, Spotify, and others), which dramatically increased the length of time its customers linger and relax at its stores, as well as the corresponding number of beverages they order. Starbucks

6 Yousef Khan, "How Burberry Embraced Digital and Transformed into a Leading Luxury Brand," Centric Digital, November 9, 2015, https://centricdigital.com/blog/digital-strategy/digital-transformation-in-traditional-fashion-burberry/.

7 Larry Dignan, "Starbucks' Digital Transformation: The Takeaways Every Enterprise Needs to Know," ZDNET, November 1, 2015, http://www.zdnet.com/article/starbucks-digital-transformation-the-takeaways-every-enterprise-needs-to-know/.

launched its MyStarbucks app in 2009, as shown in Figure 1-7. This morphed into a multi-purpose vehicle which includes the following:

- Personalized advertising and promotions.
- A digital replacement for a Starbucks card (and later fully integrated with both Apple Passbook and Apple Pay).
- A Starbucks Store locator.
- A reward-management system. The MyStarbucks Rewards program boasts over 20 million members and accounts for over 20 percent of transactions.
- A Mobile Order and Pay service that allows busy customers to "skip the line" by placing their order and paying for it while on their way to a Starbucks and then having their beverage and food ready and waiting for them to pick up and go. The Mobile Order and Pay customer experience resulted in a 17 percent increase in revenues in the first year after its release.

Figure 1-7 *Starbucks—Mobile Order and Pay*

UPS

United Parcel Service (UPS) is the world's largest package delivery company, delivering more than 19 million packages per day to over 8 million customers in more than 220 countries and territories around the world. However, customers were often frustrated to receive notices or emails to the effect that their packages would be delivered on a certain day between 8 a.m. and 6 p.m., as remaining at home for such a long window considerably inconvenienced most people.

In response to customer complaints, UPS began tracking each vehicle via GPS, not only to improve route optimizations (resulting in over 8 million gallons of fuel savings per year), but also to more accurately predict delivery windows, dramatically cutting these down to one- to two-hour slots. UPS also began enabling customers to monitor these reduced delivery windows via its mobile app. Customers now can elect to receive alerts when their delivery is imminent and can even provide the driver instructions directly from the app. These improvements in customers service via digital technologies have resulted in a dramatic increase in customer satisfaction and loyalty for UPS.

Transforming the Employee Experience

It's not only improved customer experiences that have a bottom-line impact on a business, but also improving the experience of their employees. Some of the challenges facing today's workforce include the following:

- **Information overload:** Information is still growing at exponential rates and employees can't find what they need, even with technology advances.
- **The need for speed:** With the rapid pace of today's work environment, employees increasingly need to work faster and collaborate more effectively to get their jobs done.
- **An aging workforce:** As baby boomers continue to retire, they are taking key knowledge with them, increasing the need to digitally capture their knowledge.

However, meeting these challenges with digital technologies can significantly improve the employee experience, as reported in a study by Deloitte[8] that showed increases in the following areas:

- **Employee productivity:** Organizations with strong online social networks are 7 percent more productive than those without.
- **Employee Satisfaction:** Organizations that installed social media tools internally found a median 20 percent increase in employee satisfaction.

8 Deloitte, "The Digital Workplace: Think, Share, Do," https://www2.deloitte.com/content/dam/Deloitte/mx/Documents/human-capital/The_digital_workplace.pdf.

- **Talent Attraction:** 64 percent of employees would opt for a lower-paying job if they could work away from the office.
- **Employee Retention:** When employee engagement increases, there is a corresponding increase in employee retention by up to 87 percent.

Some specific examples of companies that have harnessed digital technologies to improve employee experiences are overviewed next.

Air France

Prior to 2006, each Air France pilot, aircraft, and flight route required a unique set of on-board documentation that collectively added *60 pounds of paper* to each flight. Furthermore, critical decisions relating to safety and operations were delayed in the paper-based communications process, including the delays required to type and photocopy all the relevant information, as well as the delays in mailing these instructions and updates to each of the over 4000 pilots and 15,000 flight attendants within the organization. The collective daily operational information filled entire dedicated rooms at multiple airports that Air France serviced. To cope, Air France made the key decision to digitize all such communications. By 2013, all of the necessary information was delivered to pilots via an iPad app, dubbed Pilot Pad, as shown in Figure 1-8. Now, not only do pilots have far less to carry (as do the aircrafts, resulting in considerable fuel savings), but also whenever Air France updates a document in its library, 60 percent of affected pilots review the updates within 24 hours, thus increasing the safety and efficiency of the airline's operations.

Figure 1-8 *Air France Pilot Pad*

Additionally, pilots benefit by being able to take training via e-learning modules on their iPads, rather than trying to coordinate in-classroom training sessions, which traditionally has been very challenging, considering their extraordinary travel schedules. Also, the app allows pilots to complete non-flying duties whenever and wherever they want, making productive use of their time spent waiting in airports. The overall effect for Air France is the evolution of its flight operations into an efficient and user-friendly process, which has proved so popular with the pilots that Air France has subsequently rolled out a similar iPad-based solution for its in-flight cabin crews.

Other airlines have followed suit, such as Alaska Airlines, which estimates that its iPad-based system saves the company over 2.4 million pieces of paper overall and 25 pounds of paper per flight (which is critical in some of the remote locations serviced by the airline).

RehabCare

The 18,000 employees of RehabCare provide rehab and post-acute care services, in over 1200 hospitals and facilities across 43 states. In such an environment every minute counts and employees need to track and record every detail, including the diagnosis, treatment, and when the appointment began and ended. To meet these challenges, RehabCare equipped its staff with easy-to-use, process-driven applications on iPhone and iPad mobile devices to provide point-of-care information capture quickly and easily. Additionally, their cloud-based applications allow access to detailed patient information anytime, anywhere. RehabCare estimates it is saving millions per year, while enabling its employees to quickly capture and/or consult critical data in an intuitive manner. Benefits also extend to the patients, as the app significantly reduces patient pre-admission screening times.

Cisco

Cisco itself has been recognized for leading digital innovation in the workplace of its 70,000 employees worldwide. As a large and global organization, Cisco noticed the trends in collaboration and the need for an integrated workforce experience, and as such implemented various solutions to this effect. For example, it launched a Cisco video communication and collaboration platform to communicate more effectively, as well as enterprise social software to facilitate healthy collaboration with personalization and relevance. These programs include a connected workspace, wiki, and video blogs, expertise locator, and sales productivity, remote collaboration, and telecommuting applications.

As shown in Figure 1-9, these platforms connect to each other for an integrated and user-friendly experience. With the implementation of seven distinct collaboration programs, Cisco recorded a total of $1.052B in net benefits from collaboration solutions.

Figure 1-9 *Cisco Collaboration Tools*

Transforming Business Operations

While digital technologies can increase revenue by delivering new customer experiences and/or increasing employee productivity increases, profitability can also be increased by leveraging digitalization to streamline and economize business operations, as the following examples demonstrate.

Boeing

There are more than 6 million parts that make up a Boeing 747 aircraft, which all have to come together at precisely the right times in order to complete production. Furthermore, since these aircraft are assembled in the largest building in the world, namely Boeing's Everett Factory as shown in Figure 1-10, there's a lot of ground to cover when something goes missing. The bottom-line impact to Boeing of a misplaced or lost part, toolkit, machinery, or work-in-progress (WIP) inventory is greater than *$1 million per incident*. To reduce such losses, Boeing implemented RFID tracking along with Cisco wireless infrastructure location capabilities to instantly identify where any key part, tool, or WIP inventory is at any given time. This digital parts-tracking system reduced production delays, inventory expenses, and even government fines.

Figure 1-10 *RFID-Enabled Boeing 747 Assembly Line in Everett, Washington*

Codelco

Codelco, a Chilean state-owned mining company, is the world's largest producer of copper. Mining not only is dark, dirty, and labor-intensive process, but is also very dangerous, as was amply demonstrated by the events that captured the world's attention that unfolded in a (different company's) Chilean mine in 2010, where 33 workers were trapped underground for 68 days.

To make mining operations safer, Codelco equipped its immense mining trucks, shown in Figure 1-11, with digital technologies that allow them to drive autonomously, arriving at their destinations just-in-time and with fewer accidents than those with human drivers. Codelco then expanded the application of similar technologies to other mining equipment, making these autonomous as well. Now, many of Codelco's workers don't head down to the mine to work, but rather to the control center in the city. Mining via autonomous equipment not only improves safety, but also brings additional economic benefits to Codelco. For example, removing humans from underground mines allows Codelco to design them to different specifications, allowing Codelco to dig with less cost and with lower risk, thus opening up the possibility of exploiting ore caches that may not have been economically feasible otherwise.

Figure 1-11 *Codelco Autonomous Mining Trucks*

BC Hydro

BC Hydro is a Canadian electric utility in the province of British Columbia, and is the main electric distributor serving nearly 2 million customers. BC Hydro has installed 1.93 million smart meters since 2011 and more than 99 percent of customers now have a new meter.

Since the installation of these smart meters, BC Hydro has realized over $100 million in benefits, primarily from operational savings. Customers also benefit, as these meters have made their bills more accurate, due to reduced manual meter reads and bill estimates. Customers can also now view their hourly and daily energy use through their online account, providing them new tools to save energy and money. Furthermore, such new metering technology has laid the foundation for more widespread use of small-scale, green, distributed electricity generation including solar and wind power.

Driving Digital Transformation with the Internet of Things

With the advent of the Internet of Things (IoT), digital transformation is taking place in virtually every area of our lives. With billions of smart devices coming online every year, massive revolutions are taking place in the following fields:

- **Environmental monitoring:** IoT sensors are being used to monitor air and water quality, atmospheric and soil conditions, the movements of wildlife and their habitats, and even early warning-systems for earthquakes and tsunamis.
- **Infrastructure management:** IoT devices are being used to monitor infrastructure resources like bridges, railway tracks, wind farms, and even waste management systems. These devices can be used to monitor activity, measure structural conditions, schedule repairs and maintenance, and coordinate emergency response.

- **Manufacturing:** IoT intelligent systems are enabling the rapid manufacturing of new products, dynamic response to product demands, and real-time optimization of manufacturing production and supply chain networks. These systems can also optimize plant operations, energy operations, and health and safety.
- **Energy management:** IoT devices are being integrated into all forms of energy-consuming devices (switches, power outlets, bulbs, televisions, etc.) and are able to communicate with the utility supply company in order to effectively balance power generation and energy usage. Such devices also offer the opportunity for consumers to remotely control their devices, or centrally manage them via a cloud-based interface, and enable advanced functions like scheduling (e.g., remotely powering on or off heating systems, controlling ovens, changing lighting conditions, etc.).
- **Medical and healthcare:** IoT devices are being used to enable remote health-monitoring and emergency-notification systems. These health-monitoring devices range from blood pressure and heart rate monitors to advanced devices capable of monitoring specialized implants, such as pacemakers or advanced hearing aids. Additionally, consumer-oriented smart devices encouraging healthy living are proving very popular, such as connected scales, wearable heart monitors, step counters, etc.
- **Building and home automation:** IoT devices are being leveraged to monitor and control the mechanical, electrical, and electronic systems used in various types of buildings.
- **Transportation:** Smart devices are enabling inter- and intra-vehicular communication, smart traffic control, smart parking, electronic toll collection systems, logistics and fleet management, vehicle control, and safety and road assistance.
- **Smart cities:** There are several planned or ongoing large-scale deployments of "smart cities"—that is, cities that have nearly every element monitored and controlled by network-enabled smart devices. For example, Songdo, South Korea, the first of its kind, is a fully equipped and wired smart city, and is nearing completion. Nearly everything in this city is connected and is streaming data for machine-driven analysis, all with little or no human intervention. Also, Barcelona is a Cisco flagship smart city which integrates digital technologies to urban services (like smart parking, smart lighting, location-based analytics, etc.) and solutions (such as energy management, safety and security, and cloud exchange).

Are You Ready?

New market opportunities and business models, fast-moving disruptive threats, and an exploding IoT landscape are all driving digital transformation. As such, the relevant questions are no longer "What is digital transformation?" and "Why should you care?" but rather "Are you ready?"

The network not only is at the center of all the users, applications, and devices that are driving digital transformation, but is also the platform that can most effectively enable it. This is why Cisco has developed its new Digital Network Architecture to meet these dynamic, complex, and rapidly evolving business needs, as discussed in subsequent chapters.

Summary

This chapter discussed the "why?" behind Cisco Digital Network Architecture, which has as its goal the driving of digital transformation. The benefits of digital transformation were examined (including 9 percent greater revenues versus industry peers and 26 percent greater profits, according to Harvard Business Review), as were the threats facing businesses that are slow to transform digitally (approximately 40 percent of the top ten incumbents in each industry being faced with digital disruption within five years).

Various businesses that have transformed entire industries digitally were reviewed, including Apple, PayPal, WhatsApp, Uber, and others. Also businesses that excelled in transforming customer experience were discussed, including Burberry, Starbucks, and UPS. So too were businesses that transformed their employee experiences, including Air France, RehabCare, and even Cisco itself. Additionally, companies that digitally overhauled their operations were presented, including Boeing, Codelco, and BC Hydro.

Finally, the massive revolutionary impact of the Internet of Things was also overviewed, to illustrate that digital transformation extends far beyond the workplace and indeed is affecting virtually every area of our lives.

Thus, having discussed the business reasons supporting digital transformation, let's focus specifically on the business value of a digital network architecture as the platform to enabling such transformation.

Further Reading

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Index

Numbers

A

B

C

D

E

F

G

H

I

K

L

M

N

O

P

Q

R

S

T

U

V

W

Y

Z