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Brian S. Cohen
Nayanee Gupta
Jonathan R. Agre
Huan Lin Zhang

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POLICY INSTITUTE
1899 Pennsylvania Ave., Suite 520
Washington, DC 20006-3602

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Executive Summary

Introduction

The Federal Government is concerned with the weakening of the domestic telecommunications equipment sector and how that weakness can negatively affect economic growth and national security. In particular, three key subsectors have been identified as being at risk: optical core network, router/switch, and wireless equipment suppliers. Researchers for the IDA Science and Technology Policy Institute (STPI) were tasked to develop a framework that supports government decision makers in evaluating policy options to meet national competitiveness, innovation, and supply-chain security goals for these three critical subsectors. The intent of the framework is to enable the aggregation of various sources of information, including ongoing efforts to model key markets, into a single, consistent view that enables decision makers to better identify effective policy actions. A key hypothesis of this work is that when trends are identified that result in disruptions to an established subsector, opportunities for policies to effect change are increased, thus enabling domestic or favorable suppliers to compete and increase market share. This hypothesis would especially apply to relatively mature and stable markets, such as the telecommunications equipment industry.

Approach

The STPI research team's approach was to develop a qualitative framework for understanding how the top-level concerns and goals can be addressed by specific policy actions. Representatives from several Federal agencies were consulted to gain agreement on the high-level goals for the subsectors. A framework is defined that relates subsector goals, significant trends, candidate policy actions, and the resulting predicted outcomes. A broad set of policy actions that could be used by the government were considered in the framework including: investments in research and development (R&D) and Small Business Innovation Research (SBIR), cooperative research and production, government as early adopter or purchaser, standards activities, regulation, and trade.

Analysis Process

The framework supports the in-depth analysis of each subsector that is accomplished in two steps. First, the most important trends affecting a subsector are identified through a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis. The identified opportunities and threats become the candidates for policy actions. At the second step, specific policy actions that could best leverage the opportunity or block the threat are identified.

Findings

For the most part, the STPI research team found that the key telecommunications subsectors of optical core, router/switch, and wireless are being dominantly driven by commercial global interests. In many cases, revenue in the markets comes from large installed bases where competition takes place for long-term (5–10 years) business. As such, there is often little tactical opportunity to change the positions and strengths of companies in these markets. The most significant observation is that while there is little leverage that policy actions can have on the stable markets, there can be disruption in the markets and large portions of the market can be available for competition when there are major trends operating in a sector. It is under these circumstances that policy actions can have a more significant effect.

All three subsectors could benefit from government support via collaborative research and production facilities. Creation of a pre-competitive collaboration test center allows suppliers to test, debug, evaluate, and confirm the interoperability of their products with products from other suppliers. These centers are potentially supported under the National Institute of Standards and Technology (NIST) as well as other Federal R&D enterprises and laboratories and would operate with shared Federal and industrial funding and support. These collaboration centers can be supported through Federal R&D and as well as through arrangements like the Cooperative Research and Development Agreements (CRADAs). There legal framework for enabling industry to collaborate on research and product pre-competitively without violating anti-trust laws has been well established and employed in other sectors. We identified a series of specific collaborations:

- A test collaboration center for routers/switches using Software-Defined Networking (SDN), such as the National Science Foundation-funded Global Environment for Network Innovations (GENI) and the Department of Energy Office of Science's Energy Sciences Network (ESNet);
- A brokered photonics foundry for access to advanced affordable photonics manufacturing, (a step which has already been taken with the creation of the Integrated Photonics Manufacturing Institute);
- A prototyping collaboration for advanced Photonic Integration Circuit (PIC) and photonic applications;
- A collaboration center for Terabit Optical Networking, such as the Georgia Tech-based Terabit Optical Networking consortium;

- A test collaboration center for advanced wireless technologies such as cognitive radio for 5G wireless systems or the Model City for spectrum sharing; and
- A collaborative center for smart antenna technology development involving multiple agencies such as the Department of Defense, NASA, and private companies.

Continued investment in targeted R&D and SBIR was identified as policy actions that can accelerate innovation, new products, and new companies in all three subsectors. These targeted investments can focus on the risky leap ahead technology opportunities that are not pursued by industry. In particular, focused Federal R&D investment initiatives in these areas were identified:

- All-optical networks using PICs and silicon photonics;
- Programmable, virtualized, and intelligent optical networks;
- Innovative software for SDN functions and products;
- Wireless 4G underlying technologies such as backhaul; and
- Advanced 5G underlying technologies such as cognitive radio, small cells, and smart antennas.

The adoption of aggressive agency level roadmaps for acquisition and adoption of new technologies could accelerate the introduction of new products to market. Agencies could select key enterprise applications as pathfinders for these introductions. The government role of early adopter or advanced purchaser of products was called out in several cases:

- Terabit optical networking equipment deployed in government networks, and
- SDN products deployed in government wide-area, campus, and data center networks

The research team identified two key areas in which active government involvement in standards could make a difference: the evolution of SDN and in 5G for wireless. There are certainly existing standards for SDN, such as OpenFlow, but SDN has much broader implications for how new system architectures will be developed and used. Similarly, the path of evolution of 5G is still very much undetermined, and participation in the evolving standards and how those standards are employed globally can make a key difference to the position of U.S. suppliers in the global market.

Since the underlying trends are constantly changing, a key finding of this work is that the government should use the framework to continually monitor subsector trends as a way of identifying and updating opportunities for policy actions to have a significant impact.

Further Work

Several areas of further work were identified during this study. The framework can be enhanced by further development of the metrics for progress toward goals. The mapping between goals, metrics, trends, and policy actions should be developed and validated in a more rigorous way. Since each agency will likely have a tailored version of goals that are most important to its organization, the framework should be flexible enough to accommodate these differences. In addition, a more complete policy option analysis would need to consider other factors such as cost, time frames for achieving results, difficulty of implementation, and other practical considerations.

Integration of the ongoing quantitative modeling efforts into the evaluation of progress metrics would provide more consistent evaluations of the effects of policy actions. However, since the models are still under development, it is too early to incorporate them. Eventually, when these models are more mature and better validated, they should be integrated into the framework to evaluate metrics for the current conditions and to predict the effects of specific actions on progress toward the subsector goals.

Conclusion

The telecommunications equipment market is truly globalized, and the three identified subsectors are being driven by very large consumer and commercial markets. The U.S. Government has struggled with identifying policy actions that can influence outcomes in the face of strong global commercial forces. This study suggests that by careful identification of emerging disruptive trends and using the opportunities that arise as those trends unfold, certain policy options hold more promise for effectively achieving key goals. A qualitative framework for conducting an analysis of policy options was defined and applied and explicitly considers the effects of disruptive trends. The framework is suitable for application in other critical industries in which there are high-level concerns on the health of the domestic suppliers.

Contents

1. Introduction

A. Background

The rapidly shifting telecommunications equipment market has been largely driven by global competition in the carrier market.[1] The United States has seen its domestic carrier market consolidate, leading to increased vertical integration and a diminished supplier base.[2] Given the importance of the communications sector to the Nation's economic and national security missions, and particularly its integral role in critical infrastructure, the Federal Government would like to address the challenges facing the domestic telecommunications sector with the following three goals:[3, 4]

- Ensure industrial capability in telecommunications equipment subsectors of critical importance to U.S. economic and national security,
- Bolster the innovation ecosystem serving U.S. telecommunications equipment markets, and
- Ensure a pipeline of trusted equipment required by the domestic telecommunication infrastructure.

To address these concerns, the Defense Production Act Committee (DPAC) was tasked with assessing the market vitality and emerging trends of pertinent U.S. supply chains. Discussions with members of the DPAC have indicated three telecommunications equipment subsectors as being most at risk: the optical core network equipment subsector, the router/switch subsector, and the wireless equipment subsector.

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1 We use the term "carrier" to refer to providers of communications services, not only traditional telecommunications service providers, but also cable, cloud, Internet service and any provider of information transport services. At times, the terms carrier and telecommunications service provider may be used interchangeably. Carriers are the largest purchasers of telecommunications equipment and have a large degree of control over the equipment market.

2 Booz and Company, *World Telecommunications Outlook*, Booz and Company, 2013.

3 Federal Register website, *Executive Order 13636—Improving Critical Infrastructure Cybersecurity*, February 19, 2013, accessed October 28, 2014, http://www.gpo.gov/fdsys/pkg/FR-2013-02-19/pdf/2013-03915.pdf.

4 White House website, *Presidential Policy Directive—Critical Infrastructure Security and Resilience*, February 12, 2013, accessed October 28, 2014, http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.

B. Purpose

The Science and Technology Policy Institute (STPI) research team was asked by the White House Office of Science and Technology Policy (OSTP) to develop a framework that supports government decision makers in evaluating policy options to meet national capabilities, innovation, and supply chain security goals for the three at-risk telecommunications subsectors identified by the DPAC. This work involved conducting a top-down examination of the emerging technology and market trends in the telecommunications subsectors to identify opportunities for policy action that would support the Federal Government goals. Special emphasis is given to disruptive changes to the current technologies and market that can create opportunities for new companies and products. Policy actions that support and encourage adoption of disruptive change are emphasized as most effective in achieving the desired goals.

C. Approach

A five-step approach was developed for this study, as shown in Figure 1.

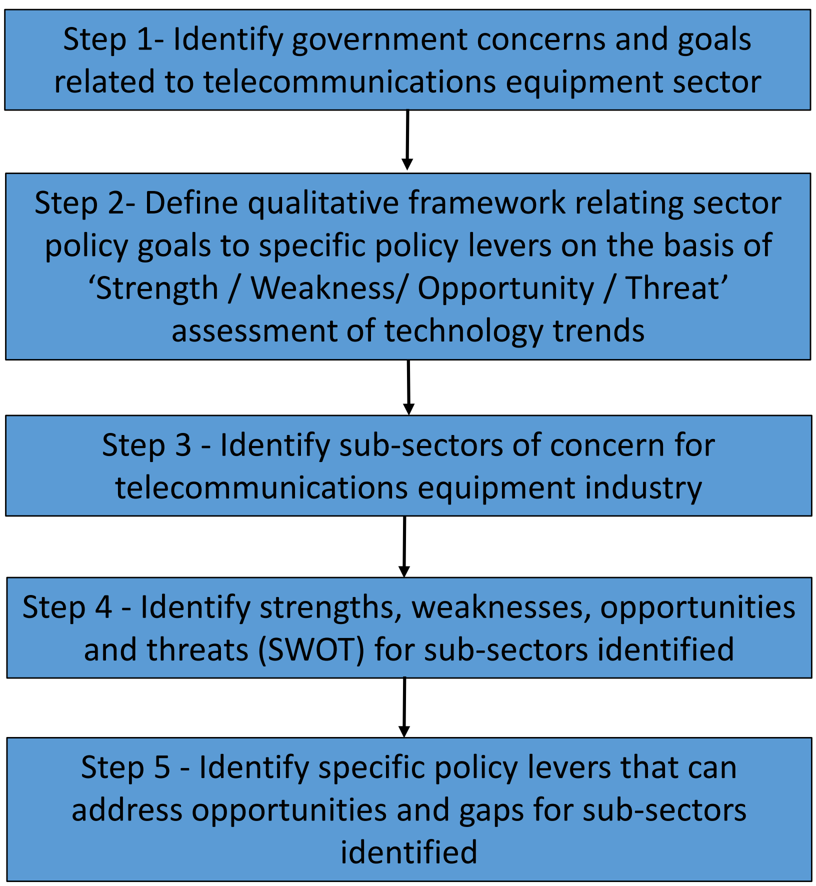

Figure 1. Five-Step Approach

The objective is to use a top-down analysis of emerging trends in the telecom equipment industry to identify targeted policy actions that could advance the goals of capability, innovation, and supply chain security. The detailed steps are as follows:

- Through literature review and interviews with Federal agency experts and other subject matter experts, identify the government goals for the telecommunications equipment industry (Section 2.A).
- Develop a qualitative framework that defines the relationships between the subsector goals, significant trends, policy actions, and desired outcomes. The framework supports an analysis process that occurs in two steps: (1) emerging trends that are anticipated to have a fundamental and long-term impact on the subsectors are identified and (2) policy actions that are applied to the trends and the resulting outcomes predicted (Section 2.B).
- For the telecommunication industry subsectors identified by the DPAC as declining in domestic capacity and global competitiveness, identify and document the current technology landscape to provide the scope for the trend analysis (Section 0).
- For each of the telecommunication subsectors, analyze the strengths, weaknesses, areas of opportunity and threats. These results are used to identify the significant technical and market trends that are affecting the sectors (Section 4.A).
- In the final step, identify specific policy actions that can address the threats and areas of opportunity to advance toward the government's goals (Section 4.B).

2. Federal Goals for the Telecommunications Sector

A. Identifying the Primary Government Goals

The primary goals of the government agencies that were identified by the team[5] for the critical subsectors were to (1) ensure industrial capability in telecommunications equipment subsectors of critical importance to U.S. economic and national security, (2) bolster the innovation ecosystem serving U.S. telecommunications equipment markets, and (3) ensure a pipeline of trusted equipment required by the domestic telecommunication infrastructure.

During the interview process, the research team found that most Federal agency policy goals were similar to the administration's goals; however, there were some differences that reflected the missions of the agency as well as differences in how the agencies operate and were able to affect outcomes. For example, one agency was concerned about its access to the most advanced technologies to support its research activities. Access to advanced technologies can be assured by a combination of capabilities and innovation improvements.

When agency-relevant concerns are translated to policy goals at a government-wide level, the three main themes that emerge are support for domestic capabilities, innovation, and supply-chain security for these critical subsectors. These policy goals are summarized without attribution and are briefly discussed in the following subsections.

1. Support Global Capabilities of U.S. Companies

The telecommunications sector is considered a central engine to major industries vital to the economic health of the United States. National competitiveness in the telecommunications sector provides a central core that enables broad competitiveness in a wide range of other industries, both upstream and downstream from the equipment sector. Emerging dependent applications such as cloud computing will not be as competitive if the underlying network support is lagging due to domestic conditions. Gaining competitiveness in the domestic market is seen as a basic requirement to being competitive in the crucial global environment. Capacity of the subsectors to produce the required goods when needed must also be considered. We have broadened the original statement of this goal

[5] These goals were identified through discussions with the sponsor, reviews of DPAC documents and interviews with representatives from the Department of Defense (DOD), Department of Energy (DOE), National Science Foundation (NSF), and other organizations.

using the term capability to include factors such as competitiveness and capacity to represent the health of a subsector.

2. Bolster Innovation Ecosystem

To improve, much less maintain a key position in these subsectors, rapid technical innovation is a requirement. Innovation is primarily generated by strong research and development (R&D) funding in the private sector and in the government and by establishing an environment for incubating new companies and products. Several agencies identified access to the leading-edge telecommunications capabilities as being vital to achieving their research mission. Providing agency-specific telecommunications infrastructure at 100G and higher was considered a critical part of the current or near-term infrastructure because of the expectation that growth in their network bandwidth requirements will outpace the general growth requirements coming from other commercial applications. Early and accelerated access to next-generation equipment and capabilities was identified as a necessary element in maintaining world-class research facilities. Having U.S. companies at the leading technological edge increases the ability of government agencies to obtain early access.

3. Ensure the Supply Chain to Preserve National Security

National security is of significant interest to many—if not most—agencies. There is concern about the cybersecurity threat and the potential for telecommunications suppliers to greatly skew the landscape in the cybersecurity arena. The telecommunications infrastructure is such a central part of underlying defense and critical infrastructure that cyber vulnerabilities in the telecommunications sector present a significant risk. The loss of domestic suppliers results in dependence on foreign sources for equipment and maintenance that can be subverted or denied. In addition, security innovations by U.S. companies may have no domestic equipment vendors that can deploy their products.

B. The Qualitative Framework for Analysis of Goals and Policy Options

The qualitative framework relates the subsector goals, technological and market trends, candidate policy actions, and resulting outcomes. The framework supports an analysis process in which (1) a detailed analysis using a Strengths, Weakness, Opportunities, Threats (SWOT) method[6] identifies the significant trends operating in each subsector and (2) policy actions are selected that are likely to cause the desired outcomes that move the subsector toward the goals.

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[6] Lawrence G. Fine, *The SWOT Analysis: Using Your Strength to Overcome Weaknesses, Using Opportunities to Overcome Threats*, First edition (CreateSpace Independent Publishing Platform, October 2009).

The framework is shown in Table 1, where the general relationships between the government's high-level concerns, goals, desired outcomes, and the range of potentially useful policy actions are illustrated. Various qualitative metrics such as "increase market share" or "increase innovation rate" are posed as the desired outcomes that are seen to provide movement toward the goal. In the future, quantitative metrics such as specific values of market share, innovation rate, year-over-year growth, or merger and acquisition activity could be used to better assess the desired outcomes as measured progress toward the goals.

Table 1. Framework Relationships between Concerns, Goals, Outcomes and Policy Actions

High-Level Concern	Related Goal	Desired Outcome	Policy Actions
Loss of domestic capability in critical subsectors increases risk to national security	Restore U.S. supplier presence and capabilities	Increase market share	Regulation, standards, trade, opportunistic support to startups
		Increase innovation rate	R&D investment, public-private partnerships, government as early adopter
Economic prosperity is at risk due to lagging health and competitiveness in equipment sector	Actions to support global capabilities of U.S. companies	Increase market share	Trade, opportunistic support to startups
		Increase innovation rate	R&D, cooperative research and production, public-private partnerships, national infrastructures
Lagging U.S. innovation leadership in critical subsectors	Bolster innovation ecosystem	Increase innovation rate	R&D investment, cooperative research and production, government as early adopter

The results of applying the framework to a subsector are a set of specific policy actions that define a strategy. For example, from a policy perspective, a strategy to bolster innovation would typically focus on the barriers to innovation (e.g., regulatory, protection of intellectual property) and the needed support systems (e.g., investment in R&D, especially by the private sector; extensive collaboration between the public and private sector; support for technology transfer). Competitiveness strategies for traded sectors include trade, tax, and technology-specific policies aimed at international competitiveness. Overall, an effective and comprehensive policy strategy at the subsector level would enable businesses to innovate, grow, and effectively compete against other firms—both domestic and global.[7]

[7] Robert D Atkinson, "*Competitiveness, Innovation and Productivity: Clearing up the Confusion*," (The Information Technology & Innovation Foundation, August 2013), accessed October 28, 2014, http://www2.itif.org/2013-competitiveness-innovation-productivity-clearing-up-confusion.pdf.

3. Overview of the Telecommunications Sector

A brief description of the telecommunications domain is provided to put the three critical equipment subsectors in the context of the overall telecommunications sector. This description is followed by a definition of the scope of the subsector products considered in each subsector that is used in the analyses in remainder of this document. A brief summary of the state of the market in each of three subsectors is also shown to indicate the relative position of the U.S. companies with respect to their global competition.

A. The Telecommunications Sector

The "wired" telecommunication world is traditionally divided into three segments: (1) the core (or wide-area) network that carries the aggregated traffic between major urban centers or large private networks (e.g., Department of Defense) across the globe; (2) the metro (or metropolitan area) network that serves a region, such as a single metropolitan area, and aggregates large-to-medium business, campuses, data centers, and consumer traffic; and (3) the access network that covers the "last-mile" and serves small businesses, individuals, and specialized services such as wireless backhaul. Together these segments connect the users to a wide variety of services, such as Internet access, Voice Over Internet Protocol (VOIP), cable TV, or virtual private networks (VPNs), offered across the global networks.

The core optical network is generally fiber based and consists of high-throughput, long-haul optical links up to several thousand kilometers long, carrying about 6 terabits per second (Tbps).[8] At the lowest physical layer, the equipment transmits data using dense wave division multiplexing (DWDM) over single mode fiber (SMF) to carry multiple streams of data using 80–160 wavelengths (channels) per fiber at up to 100G[9] rates per wavelength. The communication signals are switched among wavelength paths using optical cross connects or reconfigurable optical add drop multiplexors (ROADMs). At the link layer, there is a mix of packet and circuit-based protocols such as Synchronous Optical Networking/Synchronous Digital Hierarchy (SONET/SDH), Asynchronous Transfer Mode (ATM) (which is almost gone), Optical Transport Network (OTN), or Ethernet.

At the network layer, end-to-end routing is typically accomplished by edge routers aggregating customer traffic and directing aggregated streams to high-capacity core routers

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8 A terabit is 10^{12} bits.

9 100G refers to 100 gigabits per second (1 gigabit = 10^{9} bits).

for the highest speed links. Traditionally, the routers operated on IP-based protocols; however, for efficiency purposes, the core networks are now often using a Multiprotocol Label Switching (MPLS) protocol to carry IP, Ethernet, and other types of traffic. MPLS is more adaptable to the mix of packet- and circuit-based traffic found on the core and metro networks.

The metro layer is characterized by a more dynamic and cost-conscious architecture using ROADM equipment, primarily over SMF for shorter distances. The metro network typically supports a larger number of connection points at lower throughput and requires greater flexibility in configuring the system to support traffic bursts. Ring—and increasingly mesh—architectures provide dynamic rapid recovery and reconfiguration (e.g., in less than 50 ms) of backup links in case of failures. These architectures employ the same mix of protocols as that in the core, using scaled-down routers, although high-speed, carrier-grade Ethernet now supports a growing percentage of attachments. The capacity requirements of metro networks are quickly approaching that of the core networks due to increases in local content distribution points, data centers, and backhaul from wireless base stations.

The access network connects the end-users to the network and consists of a variety of technologies that include Passive Optical Network (PON) gear (as used in fiber to the home (FTTH)), wired and optical cable TV, wired and optical local area networks (LANs), wired digital subscriber lines (xDSL),[10] wireless access (Worldwide Interoperability for Microwave Access (WiMAX)), cellular networks, and wireless LAN (Hotspots). The equipment is mass-market driven and extremely cost sensitive, driving rapid technology changes to keep up with demand. Wired, optical access networks commonly employ less expensive photonic components such as vertical-cavity surface-emitting laser (VCSELs) over less expensive multi-mode fiber (MMF) with coarse wave division multiplexing (CWDM) in newer 10G and 100G Ethernet rollouts.

Wireless cellular networks consist of access networks (called cells) controlled by base stations that connect user devices to a carrier's cellular backbone networks. The backbone networks can employ core and metro network technologies. Base stations are connected by backhaul links that connect to metro area networks and eventually to the core networks. The wireless traffic can be routed through the cellular networks of other carriers, the telephone network, or the Internet to efficiently connect the user to the desired service.

Overall, Internet traffic is growing at a compound annual growth rate (CAGR) of 40%–50% (doubling every 2–3 years). This rate of growth is driving technology development to increase capacity in core and metro networks while using the enormous existing installed infrastructure as much as possible. For example, 40G and 100G

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[10] xDSL refers to broadband access technologies based on DSL technology.

transmission systems can use much of the existing 10G infrastructure. The evolution to even higher rates will involve more efficient transmission schemes similar to those employed in wireless systems, such as coherent transmission with advanced modulation schemes. Investment in new equipment in the core and metro networks and for the router/switch equipment is required to continue to meet the expected demand.

B. Telecommunication Subsector Products

The following three tables contain listings of the most important equipment found in the optical core, the router/switch, and wireless subsector markets that serves to define the scope of this study.

In Table 2, for the optical core subsector, we focus on optical core equipment that is using DWDM and ROADM technology for long-haul and metro networks. In Table 3, for the router/switch subsector, core and provider edge routers and switches that serve the long-haul and metro networks are included. Customer edge routers and LAN switches will not be considered. In Table 4, for the wireless subsector, the focus is on 4G LTE technology, primarily the base stations and integration with IP networks. Handset products and WiMAX are not considered further.

Table 2. Core Optical Network Equipment

Type of Optical Network	Equipment	Description
SONET/SDH	Transmission	Includes metro and long-haul
	Add/drop multiplexors (ADMs) or optical cross connects (OXCs)	Devices that attach to SONET/SDH rings and/or provide digital cross-connect (DCS) functions
	Multiservice Provisioning Platforms (MSPPs)	Supports a variety of optical and service interfaces with integrated management capabilities
DWDM	Metro transport	Terminals, optical add-drop multiplexer (OADMs), amplifiers
	Metro ROADM	ROADM technology—optical-to-electrical-to-optical (OEO) or photonic switching; may have transport capabilities; includes amplifiers
	Long-haul transport	Terminals, OADMs, amplifiers
	Long-haul ROADM	ROADM technology - OEO or photonic switching; must have transport capabilities; includes amplifiers
	Long-haul submarine line terminating equipment (SLTE)	Dry hardware only, must be purpose built for SLTE

Table 3. Router/Switch Equipment

Type of Router/Switch	Equipment	Description
IP Core Routers	High-capacity routers	Layer 3 devices deployed in service provider core/metro networks that route IP and support MPLS and pseudo–wire Ethernet services
IP Edge Routers	Medium-capacity routers	Layer 3 devices deployed at the edge of service provider core/metro networks that route IP and support services such as VPNs and aggregation (grooming) of traffic
Carrier Ethernet Switches	Enhanced Ethernet equipment for long-haul and metro	Used in service-provider networks

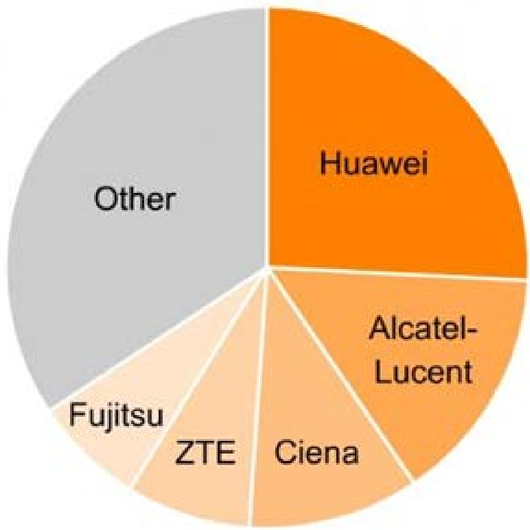
Table 4. Wireless Equipment

Type of Wireless Network	Equipment	Description
Long term Evolution (LTE)	Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)	Includes metro and long-haul
	Remote Radio Head (RRH)	Devices that attach to SONET/ SDH rings and/or provide DCS functions
	Evolved Packet Core (EPC)	Mobility Management Entity (MME) Access Gateway (LTE-GW) (includes Packet Data Network Gateway (P-GW) and Serving Gateway (S-GW))
WiMAX	Home agent	Mobile IP-like services
	ASN gateways	Access service network traffic aggregation
	802.16e,d,m base transceiver station (BTS)	WiMAX base stations

C. Market Conditions in the Subsectors

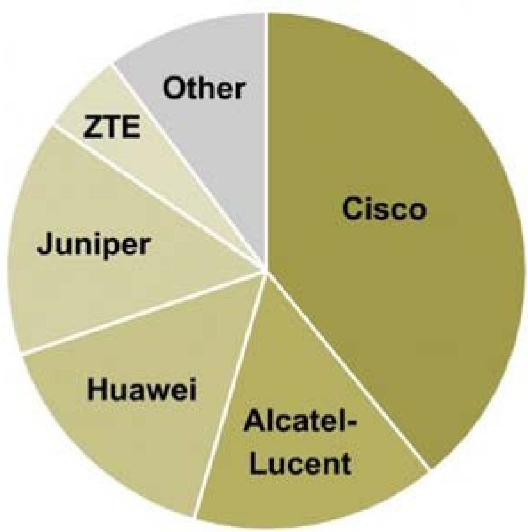
There has been a steady consolidation of suppliers in the three subsectors of interest over the last 10 years. This consolidation has been caused, in part, by a reduction in the number of carriers that purchase this equipment, the trends toward vertical integration, the tendency of carriers to stick with known suppliers, and the concentration of carriers in the developing countries.

As shown in Figure 2, the optical subsector is dominated by five companies: Huawei, Alcatel-Lucent, Ciena, ZTE, and Fujitsu. Only one company, Ciena is based in the United States. As shown in Figure 3, the Router/Switch subsector is dominated by five companies: Cisco, Alcatel-Lucent, Huawei, Juniper, and ZTE. Of these Cisco and Juniper are U.S. companies with a significant share. As shown in Figure 4, the wireless equipment market is dominated by non-U.S. companies (Ericsson, Huawei, Nokia-Siemens, and Alcatel-Lucent), and analysts suggest that further consolidation may be anticipated, possibly resulting in a third, strong network equipment provider on par with Huawei and Ericsson or a strategic partnerships between the two smaller companies.



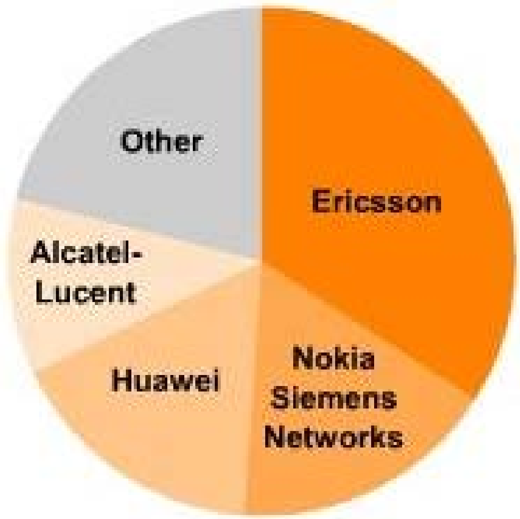
Source: Infonetics Research, *Optical Network Hardware Quarterly Market Share, Size and Forecasts* (February 2013).

Figure 2. Top Optical Network Vendors by 2012 Global Revenue Share



Source: Infonetics Research, *Infonetics & IDC: Worldwide Carrier Ethernet Switch & Router Results and Market Forecasts* (May 2013).

Figure 3. Top Five Service Provider Router and Switch Vendors by 1Q13 Global Revenue Share



Source: Infonetics Research, *Infonetics: Mobile Infrastructure Market Declines, while Mobile M2M Spending Was Up 25% Year-over-Year* (June 2013).

Figure 4. Top Four Mobile Infrastructure Vendors (Wireless Infrastructure Equipment Suppliers) by 1Q13 Global Revenue Share

4. Applying the Qualitative Analysis Framework

Fostering growth and competitiveness is a perennial policy challenge, and studies suggest that a policy-based approach should consider the constraints and ground realities of the industrial sector in question. In the case of the telecommunications equipment industry, the market is dominated by long-term acquisitions with many competitions being for contracts over a period of 5–10 years. As such, market share does not turnover very quickly even for the most competitive suppliers. Further, a large proportion of the market is outside the United States, as U.S. shares of the global market have been in a decline for a decade or more.

As a result, policy actions in the context of this sector are likely to be more effective when applied to emerging innovation and fundamental technology shifts, rather than trying to affect the competitive position in the market shares of mature technologies (a view shared by government and industry experts consulted for this task). In recognition of this situation, we have developed a framework that is opportunistic and that attempts to identify key technology trends in critical subsectors. On the basis of that framework, we suggest specific actions that can be taken early to establish domestic capability and, eventually, a competitive position in these sectors. By employing this qualitative framework, the Federal policy actions can be strategically steered toward affecting change in global market shares in an effective manner.

The application of the framework analysis process occurs in two steps: (1) identification and analysis of the trends affecting a subsector and (2) identification of policy actions that can leverage the identified trends.

A. Identifying the Trends through a SWOT Analysis

The state of the three subsectors is summarized using a form of SWOT analysis.[11] The strengths and weaknesses of the current state of the subsector are identified. Some of the important trends that are shaping—and changing—these subsectors are categorized as either opportunities or threats. The trends were identified considering the demand, technological, and market drivers that are affecting the three subsectors. Table 5, Table 6, and Table 7 give a summary of the SWOT analysis for each sector.

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[11] Fine, *The SWOT Analysis*.

Table 5. Optical Core Network Subsector—SWOT Analysis

Strengths

- Demand increasing steadily from consumers, data centers, cloud computing
- Market experiencing steady growth
- Strong research activities in academia in all-optical technology
- US company Infinera has a leading position in the PIC industry

Weaknesses

- Few US companies are major suppliers
- Purchases closely tied to carrier equipment refresh cycle

Opportunities

- Increasing the capacity of optical systems to the 100 Gbps level
- Increasing the capacity of optical systems to the 1 terabit level
- Increased metro equipment performance due to LTE, Cloud Computing
- Emerging all-optical areas such as PICs and silicon photonics provide U.S. companies a chance at establishing competitive positions at the forefront of a new technology paradigm.
- Call from the research community for SDN research into programmable, virtualized and intelligent optical networks. Some carrier buy-in.
- Development of Cloud Computing Data Centers allowing non-traditional entrants to field

Threats

- Reliance on long term contracts with carriers and carriers are reducing investments
- Increasing vertical integration by router companies integrating optical transmission equipment to their routers (and vice versa) is anticipated; this will result in consolidation, while making it harder for new entrants to break into the field
- Strong foreign competition and investment in R&D may become first to supply 1 Tbps equipment
- Even if new product lines result, manufacturing will eventually move overseas

Table 6. Router/Switch Subsector—SWOT Analysis

Strengths

- Demand increasing steadily from consumers, cloud, data centers, content distribution
- Market experiencing steady growth
- Large installed base, brand loyalty
- US companies are competitive in current market
- Non-traditional providers such as Google and Amazon are adopting SDN in data centers
- US companies have strong history of software innovation as needed for SDN
- US leading R&D and standards for SDN

Weaknesses

- Strong foreign companies are major suppliers and increasing market share
- Product cycles closely tied to carrier equipment refresh cycle
- Reluctance of incumbents to compete with own products

Opportunities

- Steady demand for new equipment, better performance due to consumers
- Increased demand for new equipment for metro networks due to LTE and cloud
- Introduction of SDN and network function virtualization can create opportunities for new entrants with innovative SDN
- Cloud Computing/Data Center providers have SDN experience that can be brought first to campus and then metro/wide area networks

Threats

- Reluctance of carriers to use non-established providers
- Increasing vertical integration by optical companies integrating routers (and vice versa) is anticipated; this will result in consolidation, while making it harder for new entrants to break into the field
- Strong foreign competition and investment in R&D are increasing their market share
- Introduction of SDN and commoditization of routers/switches can cut profits of traditional companies (current 65% margins)

Table 7. Wireless Subsector—SWOT Analysis

Strengths	Weaknesses
• Demand increasing steadily, both domestically and globally. Rural areas of US have strong growth. • Market experiencing steady growth • US has companies with strong IP (e.g., Qualcom) • US has advanced research in cognitive radio and spectrum sharing	• No US companies are major suppliers of 4G • Few opportunities for outlets to innovation • Some foreign companies have financial advantages in capturing business
Opportunities	**Threats**
• Innovation and leadership in 5G definition and standardization can leapfrog current market situation • Product innovation in advanced technologies from academia and start-ups in 5G and related technologies (e.g.,, smart antenna, small cells) • Product innovation in spectrum sharing and cognitive radio represents new market	• EU, Korea, and China are investing in definition of 5G and research into early prototypes • Foreign market strength om 4G can lock-out US innovation

Through examination of the SWOT tables, a set of seven trends were selected as being representative of the current situation in these subsectors or as causing significant changes in a subsector in the next 3 to 10 years. The trends identified are as follows:

- **Growth in user demand.** The growth in Internet traffic driven by content providers, growth in communications modes (e.g., video, mobile, machine-to-machine (M2M), eHealth and mHealth, and so forth), big data analytics, cloud computing, and data center usage patterns are resulting in significant changes in the wireless, router, and optical core segments of the telecom equipment market.
- **Increasing consolidation and vertical integration in the equipment sector.** Despite increasing demand, regulations provide a disincentive for network companies to invest in infrastructure capacity. This has put downward pressure on equipment suppliers and is driving vertical integration and further consolidation in the equipment sector, in turn increasing the vulnerability of the domestic sector to foreign competition.
- **LTE and a move to an all-IP network.** LTE is a fourth-generation wireless standard that has seen rapid adoption driven by the growing use of smart devices and increasing consumer demand for data. The infrastructure upgrade to 4G LTE requires fundamental changes to the network architecture, including a transition from a circuit-switching model to an all IP-based packet switching system.
- **Cloud computing.** As a result of telecommunications providers moving into the cloud and non-traditional and cloud providers building out high-speed networks, the role of data centers in the telecommunications infrastructure will grow in

importance. This growth is expected to increase the capacity requirement and to result in different traffic patterns.

- **Software-Defined Networking (SDN).** SDN is a promising new architecture for communication networks that moves the control of the network from the edges (routers and switches) to the center (servers). It is motivated by cloud providers redesigning networking architecture for cloud-based operations, with centralized network control that can be implemented via standard software technology.
- **All-optical networks.** Implementing all-optical networks has long been an approach to satisfying increased throughput requirements in core and metro networks. The transition from 10 Gbps to 100 Gbps per wavelength DWDM systems is currently underway for the commercial core and metro networks. The goal is to achieve 400 Gbps and 1 Tbps per wavelength commercially in the next few years.
- **Wireless 5G.** Notwithstanding the success of 4G LTE, U.S. companies are not likely to be able to penetrate this market in the near term. This realization had led to the hypothesis that there may be opportunities to capture the market on the deployment of the next generation of networks, 5G, which will likely support the Internet-of-Things (IoT)—always on and connected capability and a seamless integration of communications, processing, and storage.

In Table 8, for each trend, the main subsectors impacted by the trend, the expected response to the trend, whether the response is evolutionary or revolutionary, and time frame for that response are listed. Appendix A gives a more detailed discussion of the SWOT analysis and identification of trends.

Table 8. Trends Affecting Telecommunications Subsectors

Trend	Sector Effected	Opportunity/Threat	Evolution/ Disruption	Time Frame
Growth in Demand	Core Optical	Move to 100 Gbps	Evolution	Short
	Core Optical	Move to 1 Tbps	Evolution	Medium
	Router/Switch	Moderate market growth	Evolution	Short
	Wireless	Moderate to large growth due to rollout of LTE, global rollout of 3G	Evolution	Short
Consolidation/Vertical Integration	Core Optical	Vertical Integration, reduced rates of carrier investments	Evolution	Medium
	Router/Switch	Vertical Integration, inclusion of trans-mission equipment	Evolution	Short

Table 8. Trends Affecting Telecommunications Subsectors (Continued)

Trend	Sector Effected	Opportunity/Threat	Evolution/ Disruption	Time Frame
LTE and all IP	Wireless	Innovation in equipment	Disruption	Short
	Core Optical/ Router/Switch	Moderate market growth, increased backhaul demand	Evolution	Short
Cloud Computing	Core Optical	Increased metro performance	Evolution	Medium
	Router/Switch	Increased perfor-mance requirements	Evolution	Medium
Software Defined Networking	Router/Switch	Move to commodity hardware, software functions	Disruption	Medium
	Core Optical	Non-traditional suppliers	Disruption	Medium
All-Optical Networks	Core Optical	Product innovation using Photonic Integration Circuit (PIC) and Silicon Photonics	Disruption	Long
Wireless 5G	Wireless	Product definition	Evolution	Medium
	Wireless	Technology innova-tion (e.g., small cells, spectrum sharing, smart antenna, and so forth)	Disruption	Long

B. Identifying Policy Actions to Leverage Trends

In the preceding section, the policy analysis framework for the telecommunications equipment subsectors combined the technology trends analysis, which identified threats and areas of opportunity for emerging technologies. The next step is to consider the general classes of policy actions and identify specific policy action(s) that would address the threats/opportunities in a manner that advances capabilities, innovation, and supply chain security goals in the domestic subsectors. Appendix B gives a detailed description of the general policy classes and actions under consideration.

Summary tables of the policy actions targeted to each of the three subsectors—optical core, router/switch, and wireless—are given in Table 9, Table 10, and Table 11, respectively. A block of rows in the summary table concerns a significant trend for that sector. Within each block, each row is a related opportunity or threat followed by specific policy actions that would address the situation. The policy actions are grouped in columns according to the broad policy classes. If there is no relevant policy action, the policy columns remain blank in the row. Some of the specific policy actions occur in multiple subsectors. In this manner, each of the significant trends, opportunities and threats for emerging technologies in the subsectors are mapped to one or more policy actions, if an action is deemed appropriate, feasible and likely to have a positive effect.

Table 9. Identification of Potential Policy Actions: Optical Core Network

Trend	Threats or Areas of Opportunity	Investments, Small Business Innovation Research (SBIR)	Cooperative Research and Production	Government as early adopter	Standards Activities	Regulation	Trade
Increased carrier and user demand	Moderate market growth						[1]
All-optical networks	Emerging areas such as PICs and silicon photonics—underlying technologies for the next generations of optical networks—may allow U.S. companies to lead in all-optical networks. Companies such as Infinera have a leading position in the PIC industry	[2] [3]	[4]				
Advances in core optical technology	Programmable, virtualized and intelligent optical networks will enable flexible, efficient and high performance	[5]					
	Optical systems are needed that perform at or above the 1-terabit level		[6]	[7]			
	Increasing vertical integration of routing and optical transmission equipment suppliers is anticipated, which will result in consolidation and make it more difficult for new entrants to break into the field						

Notes:

[1] Advocate for a fairer global trade practices
[2] Targeted R&D and SBIR for PICs and silicon photonics
[3] U.S. Photonics Foundry for advanced development
[4] Consortium for accelerated all-optical product prototyping
[5] Targeted R&D and SBIR for intelligent virtualized networks
[6] Support for Georgia Tech Terabit Optical Networking
[7] Government early adopter of terabit networking

Table 10. Identification of Potential Policy Actions: Routers/Switches

Trend	Threats or Areas of Opportunity	Investments, SBIR	Cooperative Research and Production	Government as early adopter	Standards Activities	Regulation	Trade
Introduction of SDN	Installed base, reluctance of carriers to deploy a new technology with non-established suppliers; however, Large telecom operators planning adoption of SDN (e.g., AT&Ts Domain 2.0)		[1]	[2]	[3]		
	Lowered barrier to entry to network routing and network maintenance market for data center networking, campus area networks, and soon wide area backbone networks		[1]	[2]			
	Major opportunities for newer companies to offer innovative networking products based on software functions	[4]	[5]				
	Threat to traditional hardware oriented router and switch companies as data networks could become commodity business in 5 years, undermining competitive differentiator (65% margins) of U.S. companies						
	A vigorous ecosystem enabling SDN innovation will be impeded by proprietary interoperation interfaces				[3]		

Notes:

[1] Collaboration center for SDN product evaluation
[2] Government early adopter of SDN products
[3] Support SDN standardization efforts
[4] Targeted R&D and SBIR for innovative software solutions
[5] Pre-competitive center for SDN product development

Table 11. Identification of Potential Policy Actions: Wireless

Trend	Threats or Areas of Opportunity	Investments, SBIR	Cooperative Research and Production	Government as early adopter	Standards Activities	Regulation	Trade
LTE and move to all-IP networks	Infrastructure upgrade/replacement— shift toward fiber connections to tower and other technologies for offloading traffic	[1]				[2]	[3]
Wireless 5G and small cell technology	Support of new companies in the wireless market such as small cells, deployment and management of WiFi offloading (e.g., Ruckus); interference mitigation techniques; Cognitive Radio; Spectrum sharing	[4]	[5]				[6]
	Improved antenna systems are needed for better efficiency, performance and lower power operation for wireless	[7]	[8]				
	Support for international standards activities to define key properties of 5G				[9]		

Notes:

[1] Targeted R&D and SBIR for underlying 4G technologies
[2] Regulatory decisions on net neutrality, spectrum auctions
[3] Fair trade practices that level the global playing field
[4] Targeted R&D and SBIR for new 5G technologies
[5] Collaborative center for 5G such as the Federal Communications Commission (FCC)/National Telecommunications and Information Administration (NTIA) Model City
[6] Favorable regulations on spectrum sharing
[7] Targeted R&D and SBIR for smart antennas
[8] Collaborative center for smart antennas
[9] Support for 5G definition and global standardization

For the optical core network in Table 9, three trends are included: increased demand, all-optical networks, and advances in core technologies. For increased demand, resulting in moderate market growth, the only effective policy action identified was [1][12] advocate for fairer trade practices to level the competiveness of the market. For all-optical networks, opportunities in PICs and silicon photonics may allow US companies to gain future market share. This can be supported by several specific policy actions: policy action [2] refers to targeted R&D and SBIR support for PICs and silicon photonics, [3] calls for a U.S. brokered photonics foundry to enhance access to advanced affordable photonics manufacturing, and [4] calls to establish an National Cooperative Research and Production Act (NCRPA) consortium with Federal participation for accelerated prototyping of advanced photonic and PIC technologies inserted into all-optical network equipment. To address opportunities due to advancing core technologies, the specific policy actions include [5] targeted R&D/SBIR investment for intelligent virtualized networks, [6] support for collaboration activities such as the Georgia Tech Terabit Optical Networking Consortium,[13] and [7] government should act as an early adopter for terabit networking equipment in their networks and support U.S. companies such as Infinera. No practical policy actions were associated with the ongoing vertical integration in the subsector.

For the router/switch summary in Table 10, the SDN trend is the major source of disruptive change. However, large telecommunications suppliers such as AT&T have announced a commitment to this technology, providing a window of opportunity for policy intervention to accelerate this shift to a new technology. To counter the threat of carriers reluctant to deploy new technology with non-established suppliers because of pre-existing long-term contracts and other installed base issues, the policy options identified include [1] creating a public/private collaborative test center for SDN product evaluation and interoperation, [2] having the government as early adopter of SDN products and incorporation of SDN into their networks, and [3] increasing standards activities related to SDN to give US companies a better global standing. SDN also presents an opportunity for new companies to enter the market due to lowered barriers of entry presented by software-based solutions and policy actions to further this are similar—[1] access to a test center for new products and [2] government use of products from new vendors. To leverage U.S. advantages in software development capabilities, policy actions are [4] targeted R&D and SBIRs to increase software innovation development and [5] establishment of a pre-competitive center for software-based product development. For the opportunity of creating the SDN development/production ecosystem through leveraging the U.S. lead in

[12] The numbers in brackets (e.g., [1], [2], [3], and so forth) refer to policy actions, which are included in and described at the end of each table.

[13] Georgia Tech Terabit Optical Networking Consortium, http://100g.gatech.edu/.

standards, the policy action [3] supporting more standardization activity can sustain the U.S. leading role. No policy action was selected to counter the threat to the current market.

For the wireless subsector in Table 11, policy actions are summarized for the two trends of LTE All-IP Networks and Wireless 5G. For the LTE and All-IP Networks, there are opportunities due to the resulting infrastructure upgrade for new niche products. Because this trend is a more evolutionary and no strong U.S. companies are involved, the policy actions include [1] investments in targeted R&D and SBIR for enhanced novel underlying technologies (e.g., backhaul), [2] regulations such as net neutrality and spectrum allocations, and [3] fair trade practices that level the global playing field. The Wireless 5G trend creates opportunities for new companies in emerging cellular technologies and policy actions of [4] targeted R&D and SBIR to accelerate the development of new products in areas such as cognitive radio and small cells and [5] a collaboration facility such as the FCC-NTIA Model City concept for spectrum sharing[14] should be pursued. In addition, support for advanced spectrum sharing can be boosted by [6] favorable regulations from the FCC and NTIA. Similarly, smart antennas are a multi-market technology that can benefit from [4] targeted R&D and SBIR investment and [1] a collaborative test center that can draw from telecommunications, defense, space and other public/private participants. Currently, the threat that the U.S. companies are lagging in 5G standardization can be addressed through policy action [10] to greatly increase U.S. participation in global 5G definition and standards.

The policy options considered in this analysis favor those that support an innovation strategy (e.g., focusing on R&D investments, SBIR, cooperative research and production, and regulatory barriers to innovation) and a competitiveness strategy (e.g., government adoption or purchase, financing, standards activities and trade), and, as such, the combined set of policy actions support the U.S. Government's overall goal of restoring U.S. supplier capabilities, increasing innovation and competitiveness of the sector, and ensuring that companies remain strong enough in the subsectors for a reliable domestic supply chain.

[14] FCC and NTIA, "Model City for Demonstrating and valuating Advanced Sharing Technologies," (Washington, DC: July 11, 2014), accessed October 28, 2014, https://apps.fcc.gov/edocs_public/attachmatch/DA-14-981A1.pdf.

5. Findings and Follow-Up Work

A. Specific Policy Actions Identified

For the most part, the STPI research team found that the key telecommunications subsectors of optical core, router/switch, and wireless are being dominantly driven by commercial global interests. In many cases, revenue in the markets comes from large installed bases where competition takes place for long-term (5–10 years) business. As such, there is often little tactical opportunity to change the positions and strengths of companies in these markets. However, there are areas where competitiveness and innovation can be influenced.

The most significant observation is that while there is little leverage that policy actions can have on the stable markets, there can be disruption in the markets and large portions of the market can be available for competition when there are major trends operating in a sector. It is under these circumstances that policy actions can have the biggest effect.

Collaborative research and production was a policy action that spanned all three subsectors. Creation of a pre-competitive collaboration test center allows suppliers to test, debug, evaluate, and confirm the interoperability of their products with products from other suppliers. These centers are potentially supported under the National Institute of Standards and Technology (NIST) as well as other Federal R&D enterprises and laboratories and would operate with shared Federal and industrial funding and support. These collaboration centers can be supported through Federal R&D and as well as through arrangements like the Cooperative Research and Development Agreements (CRADAs)[15] The NCRPA of 1993[16] establishes ways that companies can collaborate pre-competitively without violating anti-trust laws. Unfortunately, collaborative research and production has to be led by industry, and, while the government can encourage and help, there is little that government can do if industry is unwilling to come together to establish the necessary consortiums to make it happen. We identified a series of specific collaborations:

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[15] Wright Patterson Air Force Base (WPAFB), "*What is a Cooperative Research and Development Agreements (CRADAs)*," accessed October 28, 2014, http://www.wpafb.af.mil/shared/media/document/AFD-070905-013.pdf.

[16] Justice Department Anti-Trust Division Manual, "*The National Cooperative Research and Production Act of 1993*," accessed October 28, 2014, http://www.justice.gov/atr/foia/divisionmanual/204293.htm.

- A test collaboration center for routers/switches using SDN, such as the National Science Foundation-funded Global Environment for Network Innovations (GENI)[17] and the DOE Office of Science's Energy Sciences Network (ESNet);[18]
- A brokered photonics foundry for access to advanced affordable photonics manufacturing;
- A prototyping collaboration for advanced PIC and photonic applications, a step that has already been taken with the creation of the Integrated Photonics Manufacturing Institute);[19]
- A collaboration center for Terabit Optical Networking, such as the Georgia Tech-based Terabit Optical Networking consortium;[20]
- A test collaboration center for advanced wireless technologies such as cognitive radio for 5G wireless systems or the Model City for spectrum sharing; and
- A collaborative center for smart antenna technology development involving multiple agencies such as DOD, NASA, and private companies.

One immediate action that could be considered is moving to have direct government collaboration and support for consortia that exist. In the other areas, there will be a need to help cultivate the necessary industrial consortium to undertake those efforts.

Continued investment in targeted R&D and SBIR was identified as a policy action that can accelerate innovation, new products, and new companies in all three subsectors.

[17] The Global Environment for Network Innovations (GENI) is a nationwide proof-of-concept project that now links nine U.S. universities, including Stanford, University of Washington, Indiana University, University of Wisconsin, Georgia Tech, Clemson, Rutgers, and Princeton. A virtual laboratory for exploring future internet technologies and protocols at scale on shared, heterogeneous and highly instrumented infrastructure, GENI allows researchers to test new ideas at scale with real traffic. Software Defined Networking and OpenFlow have become an important part of the GENI backbone, helping GENI to achieve its goal of experimentation at scale with real applications and users. See http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501055.

[18] ESNet is a high-speed network connecting the DOE laboratories to over 100 other research and collaboration networks worldwide. ESNet also serves as a testbed for 100G and OpenFlow technologies. Companies such as Infinera and Brocade have successfully demonstrated Software-Defined Networking technologies on this network. See http://www.es.net/.

[19] The Integrated Photonics Manufacturing Institute (IPMI) will focus on developing an end-to-end photonics 'ecosystem' in the U.S., including domestic foundry access, integrated design tools, automated packaging, assembly and test, and workforce development. The IPMI was announced by the White House on October 3, 2014 (http://www.whitehouse.gov/the-press-office/2014/10/03/fact-sheet-president-obama-announces-new-manufacturing-innovation-instit).

[20] The Georgia Tech Consortium was formed lead advances in the quantitative understanding of optical, electronic and signaling interactions to enable the development of components, systems and design rules for dynamically reconfigurable 100Gbps and Terabit networks. It is supported by more than 12 companies including component manufacturers, software companies, fiber manufactures, equipment manufacturers and service providers. See http://100g.gatech.edu/.

These targeted investments can focus on the risky leap ahead technology opportunities that are not pursued by industry. In particular, focused Federal R&D investments initiatives in the following areas were identified:

- All-optical networks using PICs and silicon photonics;
- Programmable, virtualized, and intelligent optical networks;
- Innovative software for SDN functions and products;
- Wireless 4G underlying technologies, such as backhaul; and
- Advanced 5G underlying technologies, such as cognitive radio, small cells, and smart antennas.

The government could acquire products when they are first available and accelerate their introduction to the market. The adoption of aggressive agency level roadmaps for acquisition and adoption of new technologies could accelerate the introduction of new products to market. Specific government or government-identified data centers, organizations, or communications infrastructure are available that could be enhanced with these new products. Agencies could select these key enterprise applications as pathfinders for these introductions. The government role of early adopter or advanced purchaser of products was called out in several cases:

- Terabit optical networking equipment deployed in government networks, and
- SDN products deployed in government wide area, campus, and data center networks.

Another key policy action identified was to support the standards that often have a key role in defining the market. Enhanced standards could encourage more vigorous competition by discouraging vertical integration and turn-key solution suppliers. Government participation and encouragement of standards activities and aggressive international trade positions on standards, including regulation and procurement activities calling for and preferring standards, can assist in market penetration. The research team identified two key areas in which active government involvement in standards could make a difference: in the evolution of SDN and in 5G for wireless. There are certainly existing standards for SDN such as OpenFlow, but SDN has much broader implications for how new system architectures will be developed and used. The active participation and encouragement of U.S. industry could make a difference in the competitiveness in these important markets. Also, similarly, the path of evolution of 5G is still undetermined, and participation in the evolving standards and how those standards are employed globally can make a key difference to the position of U.S. suppliers in the global market.

Since the underlying trends are constantly changing, a key finding of this work is that the government should use this or a similar framework to continually monitor subsector trends as a way of identifying and updating opportunities for policy actions that will have a significant impact.

B. Further Work

This study interviewed selected representatives of key government agencies. From those interviews, a basic understanding of the high-level concerns, goals, and desired outcomes and an initial mapping of how policy actions might affect those concerns and goals were developed. This relationship, shown in Table 1, should be developed and validated in a more rigorous way to define the relationship between goals and key metrics of progress toward goals. In addition, each agency will likely have a tailored picture of the concerns and goals and specific desired outcomes that are most important to its organization. A method for helping those organizations tailor this framework and use it for agency level decisions could be developed.

The qualitative framework described could be expanded in several directions. A more complete policy option analysis should more rigorously consider additional factors such as cost, time frames for achieving results, difficulty of implementation, and other practical considerations.

The results of the ongoing quantitative modeling efforts have been helpful in informing this qualitative framework, but the models are still under development. Eventually, when the models are more mature and better validated, they should be integrated into the qualitative framework to evaluate metrics for the current conditions and to predict the outcomes and effects of specific actions on progress toward the subsector goals. Of most importance would be validating a methodology for evaluating the effectiveness of a broad range of potential policy actions based on historical observations. The models could be validated by looking at retrospective periods in time during which major trends have occurred. Using model predictions to understand how much certain policy actions become amplified during past trends would be an important validation of the predictive capabilities of the models. Lastly, the qualitative framework could be applied to other industrial sectors to validate its utility.

6. Summary

The Federal Government is concerned with the weakening of the domestic telecommunications equipment sector and how this trend can negatively affect economic growth and national security. This document assesses three key critical subsectors of the telecommunications equipment industry: optical core network, router/switch, and wireless equipment, using a framework that supports government decision makers in evaluating policy options to meet national industrial capability, innovation, and supply-chain security goals for these subsectors. Previous and ongoing work by the DPAC has been developing a quantitative model approach that employs historical data to predict the effect of policy actions of key outcomes. The STPI research team's approach was to develop a qualitative framework for understanding how the top-level concerns and goals of the government can be addressed by specific policy actions. A key element of the framework is the hypothesis that subsector trends, driven by demand, technology, or market forces, can create opportunities for which policy actions are more effective, especially in mature and stable markets such as telecommunications. For example, when a technology innovation results in a massive replacement of equipment, new competitors may be able to gain market share. A broad series of policy classes that could be used by the government are considered in the framework, including investments in R&D, cooperative research and production, government as early adopter or purchaser, standards activities, regulation, and trade.

This framework analysis process is applied in two steps. First, the most important trends affecting a subsector are identified by performing a SWOT analysis. The identified opportunities and threats are then candidates for policy actions. At the second step, the team identifies specific and effective policy actions that could be considered to take advantage of the opportunity or block the threat.

The telecommunications equipment market is truly globalized, and the three identified subsectors are being driven by large consumer and commercial markets. The U.S. Government has struggled with identifying policy actions that can influence outcomes in the face of those strong global commercial forces. The outcome of this project suggests that by careful identification of emerging disruptive trends and using the opportunities that arise as those trends unfold, certain policy options hold more promise for effectively achieving key goals. The framework is suitable for application in other critical industries in which there are high-level concerns on the health of the domestic suppliers.

Appendix A.
Trends Analysis

The state of the three telecommunications subsectors—optical core, router/switch, and wireless—were examined from the perspective of the important trends that are shaping—and changing—these subsectors. The main trends were identified by considering the demand, technological, and market drivers that are affecting the three subsectors.

As a result of the analysis, seven major trends were identified as being representative of the current situation in these subsectors or as being likely to cause significant changes in the next 3 to 10 years. Many of the trends are affecting all three subsectors while others are primarily affecting one or two. These seven trends, expanded later in this appendix, will impact on or more the main subsectors and may generate a response that is either is evolutionary or revolutionary and may offer opportunities for policy actions to have increased effectiveness.

The following sections are organized around a discussion of the drivers of change operating in the telecommunications subsectors, the seven identified trends, and then a summary of the trend analysis organized from the perspective of the three subsectors. The subsector perspective uses a form of the Strength, Weakness, Opportunity, Threat (SWOT) analysis method commonly employed in various forms of strategic analysis.[21] The SWOT analysis typically divides the issues into internal organizational strengths and weaknesses and external opportunities and threats. In our analysis, the strengths and weaknesses are determined relative to the current state of each subsector. The effects of the trends identified earlier are categorized as either opportunities or threats.

Drivers of Change

In this section, we describe an approach for analyzing some key emerging technology and market trends in the telecommunications equipment sector. These short-, medium-, and long-term trends are analyzed by looking at a consistent set of drivers—such as user demand, research and development (R&D) activities, market conditions, standardization activities—that typically affect the trajectory of technological, market and policy changes.

[21] Fine, *The SWOT Analysis*.

The team analyzed change in terms of the drivers or processes that take place in innovation systems and that result in trends of technological change and changes in competitive positions. Here, an innovation system denotes "… *The network of institutions in the public and private sectors whose activities and interactions initiate, modify and diffuse new technologies*"[22]. This approach is based on the theory that the rate and direction of technological change is determined not just by competition between different technologies themselves, but also by factors external to the technology itself. For example, the prevailing technology has benefitted from evolutionary improvements ranging from cost-performance characteristics and user adoption to infrastructure and capital.

The qualitative framework for analyzing subsector trends used here is organized in terms of the following types of drivers of change:

- Demand-related drivers,
- Technological innovation related drivers, and
- Drivers related to market conditions.

Table A-1 lists the full set of factors that drive or have an impact on change, and form the basis of the qualitative analysis of subsector trends and their implications.

Table A-1. Main Drivers of Change in Telecommunications Subsectors

Types of Drivers for Change	Drivers for Change
Demand	• Growing customer demand • Technology adoption • Changes in technology usage patterns • Internet trends, shifts in Information Technology (IT) landscape
Technological innovation	• Long-term basic R&D goals and investments • Major/disruptive technological innovations • Technology adoption and diffusion • Installed capacity and sunk cost
Market conditions	• Market consolidation and intensity of competition • Market distortions and aggressive pricing • Trends in company investments and capital expenditure (capex) • Standards and interoperability • Regulations

[22] Christopher Freeman, *Technology and Economic Performance: Lessons from Japan* (London: Pinter, 1987).

Demand is considered to be one of the most important determinants of an innovation process, and the successful adoption of a technology depends on meeting changing customer needs at a price he/she can afford. For decades, innovations in technology—and particularly in the telecommunications sector—were led by business enterprises, as the purchasing power of the enterprise was necessary to break down technical barriers to success. However, over the past decade, advances in computing power have democratized innovation across the information and communication technology sectors, where the most innovative technologies are emerging to satisfy consumer, and not enterprise demand.

The growth of Internet traffic, mobile data, and machine-to-machine (M2M) communications are some of the biggest drivers for advances in communication technologies today, while disruptive technologies such a Skype (a free voice-over-IP (VOIP) service) are changing established market structure and norms of innovation in the field. In addition, many of the emerging paradigms of the IT world, such as cloud computing, pervasive computing, and the Internet-of-Things (IoT) have significant implications for the technology evolution in the telecommunica tions sector.

Next, we look at trends that are driven by *technological-innovation* in some detail to identify anticipated shifts that will impact the telecommunications supplier base. This includes looking at the following:

- Long-term, basic R&D activities and investments, where the goal is to effect a paradigm shift to a fundamentally new technology model. This research is typically conducted at a pre-competitive level, where the government can play an important funding role.
- Major technological innovations that change the structure and operating model of the industry, while unlocking efficiencies and reducing costs for the consumer. Such technological advances can potentially reconfigure the supply-chain of the industry, creating opportunities for startups and small companies in multiple areas.
- Adoption and diffusion of evolutionary technology trends and advantages of installed capacity and sunk cost, which is particularly significant for incumbent companies in the telecommunications sector.

Market conditions and major firms’ activities can put pressure on competitors, suppliers, or other parts of the sector. For example, lowered operating margins or a risky investment climate can lead to consolidation, reducing competition and driving toward vertical integration, thereby hurting suppliers. Aggressive pricing that leads to market distortion, monopolistic behavior, and other uncompetitive strategies of firms are other market-related factors that can exert pressure on competitors and component suppliers.

Interoperability and standards-setting activities play a significant role in the telecommunications sector, and these factors can either be market driven or policy driven, depending on the regulatory environment in a country or region.

In the telecommunications sector, regulations are cited as having a major impact on profits and the willingness to invest in infrastructure maintenance and upgrades. In figure A-1, it is shown how the profits vary by the regulatory environment. This variation clearly has an impact on the lower tiered suppliers to the telecommunications and media carriers, while the content-providing companies are seen to be reaping most of the profits. This situation is causing disruptions to the traditional telecommunications market as carriers move to establish themselves as content providing or other service providing businesses.

The set of drivers described here is used as part of the SWOT analysis to identify and analyze emerging trends impacting the telecommunications subsectors. As technological innovations evolve in response to both improvements in performance as well as external drivers, they create opportunities for policy action in a way that can eventually improve (or hinder) the overall health and competitiveness of the sector.

SWOT Analysis of Subsectors

A form of SWOT analysis[23] is used to separate the data on the current state of the subsector and the trends that are operating on the subsector. Although not a conventional use of a SWOT analysis, the format is useful to understand both how the trends can impact the subsector and what is likely to occur if no policy actions are taken. The SWOT analysis typically divides the issues into internal organizational strengths and weaknesses and external opportunities and threats. In our analysis, the strengths and weaknesses are determined relative to the current state of each subsector. The trends are identified by considering the drivers operating on the subsector and the effects of these trends are categorized as opportunities or threats. Table A-2, Table A-3, and Table A-4 contain the summarized information from the SWOT analysis for the three subsectors: optical core network, router/switch, and wireless, respectively.

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[23] Albert Humphrey, "*SWOT Analysis for Management Consulting*," SRI Alumni Newsletter (SRI International, December 2005).

Table A-2. Optical Core Network Subsector—Strengths, Weaknesses, Opportunities, Threats

Strengths

- Demand increasing steadily from consumers, data centers, cloud computing
- Market experiencing steady growth
- Strong research activities in academia in all-optical technology
- US company Infinera has a leading position in the PIC industry

Weaknesses

- Few US companies are major suppliers
- Purchases closely tied to carrier equipment refresh cycle

Opportunities

- Increasing the capacity of optical systems to the 100 Gbps level
- Increasing the capacity of optical systems to the 1 terabit level
- Increased metro equipment performance due to LTE, Cloud Computing
- Emerging all-optical areas such as PICs and silicon photonics provide U.S. companies a chance at establishing competitive positions at the forefront of a new technology paradigm.
- Call from the research community for SDN research into programmable, virtualized and intelligent optical networks. Some carrier buy-in.
- Development of Cloud Computing Data Centers allowing non-traditional entrants to field

Threats

- Reliance on long term contracts with carriers and carriers are reducing investments
- Increasing vertical integration by router companies integrating optical transmission equipment to their routers (and vice versa) is anticipated; this will result in consolidation, while making it harder for new entrants to break into the field
- Strong foreign competition and investment in R&D may become first to supply 1 Tbps equipment
- Even if new product lines result, manufacturing will eventually move overseas

Table A-3. Router/Switch Subsector—Strengths, Weaknesses, Opportunities, Threats

Strengths

- Demand increasing steadily from consumers, cloud, data centers, content distribution
- Market experiencing steady growth
- Large installed base, brand loyalty
- US companies are competitive in current market
- Non-traditional providers such as Google and Amazon are adopting SDN in data centers
- US companies have strong history of software innovation as needed for SDN
- US leading R&D and standards for SDN

Weaknesses

- Strong foreign companies are major suppliers and increasing market share
- Product cycles closely tied to carrier equipment refresh cycle
- Reluctance of incumbents to compete with own products

Opportunities

- Steady demand for new equipment, better performance due to consumers
- Increased demand for new equipment for metro networks due to LTE and cloud
- Introduction of SDN and network function virtualization can create opportunities for new entrants with innovative SDN
- Cloud Computing/Data Center providers have SDN experience that can be brought first to campus and then metro/wide area networks

Threats

- Reluctance of carriers to use non-established providers
- Increasing vertical integration by optical companies integrating routers (and vice versa) is anticipated; this will result in consolidation, while making it harder for new entrants to break into the field
- Strong foreign competition and investment in R&D are increasing their market share
- Introduction of SDN and commoditization of routers/switches can cut profits of traditional companies (current 65% margins)

Table A-4. Wireless Subsector—Strengths, Weaknesses, Opportunities, Threats

Strengths	Weaknesses
• Demand increasing steadily, both domestically and globally. Rural areas of US have strong growth. • Market experiencing steady growth • US has companies with strong IP (e.g., Qualcom) • US has advanced research in cognitive radio and spectrum sharing	• No US companies are major suppliers of 4G • Few opportunities for outlets to innovation • Some foreign companies have financial advantages in capturing business
Opportunities	**Threats**
• Innovation and leadership in 5G definition and standardization can leapfrog current market situation • Product innovation in advanced technologies from academia and start-ups in 5G and related technologies (e.g.,, smart antenna, small cells) • Product innovation in spectrum sharing and cognitive radio represents new market	• EU, Korea, and China are investing in definition of 5G and research into early prototypes • Foreign market strength om 4G can lock-out US innovation

The Seven Trends

As a result of the SWOT analysis, seven trends were selected as key forces of change in the subsectors. Some of the trends cut across multiple subsectors while others primarily affect a single subsector.

Growth/Change in Demand

With the growth of the Internet Age, the telecommunications sector has evolved into much more than a voice carrier as Internet traffic grows exponentially and smartphones are emerging as the preeminent interface to digital content. According to the Cisco Visual networking index, Global IP traffic has increased fivefold over the past 5 years and will increase threefold over the next 5 years. Overall, IP traffic will grow at a compound annual growth rate (CAGR) of 21% from 2013 to 2018. Much of this growth is driven by content providers, growth in communications modes (e.g., video, mobile, M2M, eHealth and mHealth, and so forth), big data analytics, cloud computing, and data center usage patterns.

With the global growth of mobile computing, mobile data traffic will increase eleven-fold between 2013 and 2018, growing three times faster than fixed IP traffic over this period. Mobile data traffic will grow at a CAGR of 61% between 2013 and 2018, reaching 15.9 exabytes per month by 2018. Wireless infrastructure, which already accounts for 43% of total telecommunications infrastructure capital expenditure (capex), will increase its overall share as spending continues to shift away from fixed infrastructure. As a consequence, the rollout of Long-Term Evolution (LTE) networks in Europe and North America and 3G deployments in India and South America will be key drivers of overall equipment revenues.

Most of the data increases are large, continuous “elephant flows” that result from the increase in video usage. Globally, IP video traffic will be 79% of all IP traffic (business and consumer) by 2018, up from 66% in 2013.[24] Content delivery network (CDN) traffic will deliver over half of all Internet video traffic by 2018. By 2018, 67% of all Internet video traffic will cross content delivery networks, up from 53% in 2013.

Metro traffic will grow nearly twice as fast as long-haul traffic from 2013 to 2018—surpassing long-haul traffic in 2015—and will account for 62% of total IP traffic by 2018. The higher growth in metro networks is due, in part, to the increasingly significant role of CDNs, which bypass long-haul links and deliver traffic to metro and regional backbones. There will be a need for denser network architectures, particularly toward the edge, as cellular systems migrate toward small cells (pico and femto) networks, as well as the increasing use of WiFi hotspots to offload the mobile data from the cellular network to the optical core.

These demands are driving significant changes in the optical core, router/switch, and wireless segments of the telecommunications market and resulting in technological innovations that continue to provide greater value to the user at lower cost.

Continuing Consolidation in Network Equipment Sector

Major telecommunications equipment suppliers in the United States and the European Union (EU) have been losing market share to Asian competitors and IT service providers for some time now. Despite increasing demand, regulations provide a disincentive for network companies to invest in infrastructure capacity. The fixed infrastructure segment (slowed by regulatory uncertainty) is seeing a trend that includes sharing network investments to realize the next generation of optical networking equipment and, in some cases, the cellular infrastructure. This trend has put downward pressure on equipment suppliers and is driving vertical integration and further consolidation in the component sector, as smaller suppliers have become acquisition targets.[25]

An example of this is shown in Figure A-1, where the effect of regulation is propagated through technology and telecommunication providers and to the customer. Since telecommunications is a regulated sector, regulation-related uncertainty has an impact on profit, R&D, and other long-term investments.

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[24] This percentage does not include the amount of video exchanged through peer-to-peer (P2P) file-sharing. The sum of all forms of video (TV, video on demand (VoD), Internet, and P2P) will continue to be in the range of 80 to 90% of global consumer traffic by 2018.

[25] Booz and Company, *World Telecommunications Outlook*, Booz and Company, 2013.

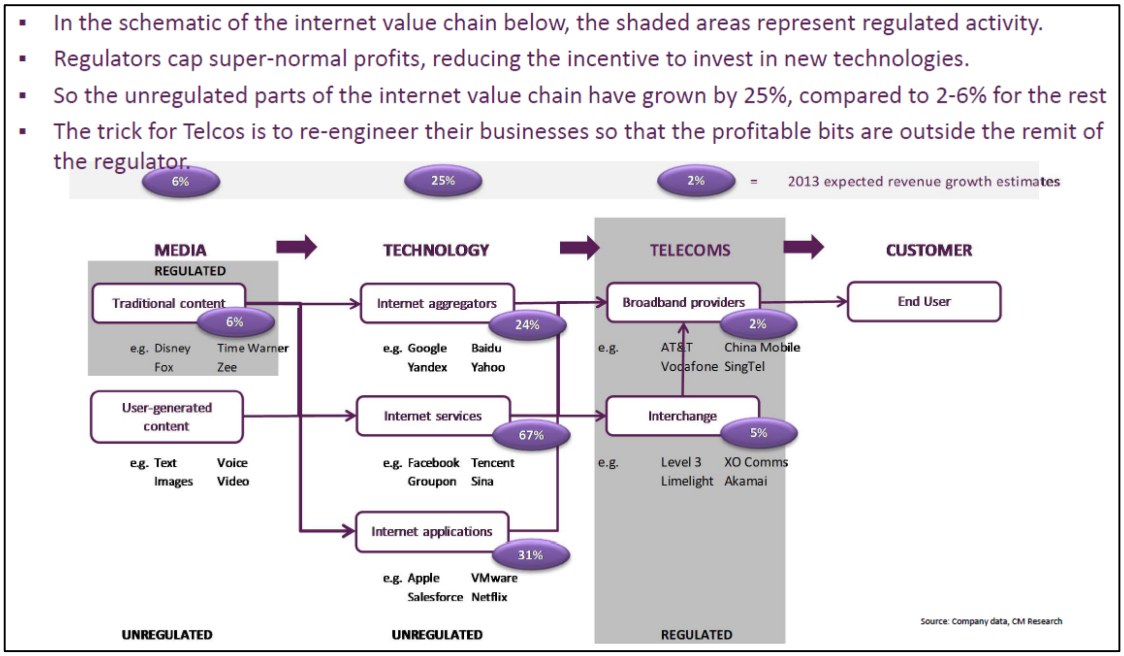


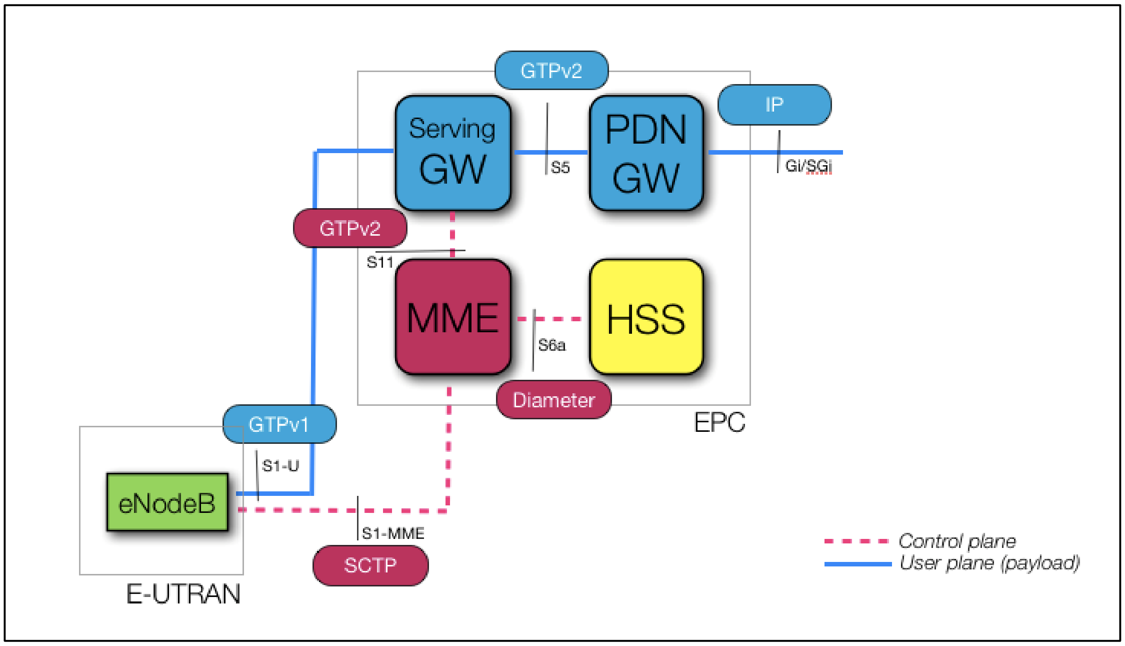
Figure A-1. Effect of Regulation on Content-Providing and Telecommunications Industries

The optical subsector is dominated by five companies: Huawei, Alcatel-Lucent, Ciena, ZTE, and Fujitsu. Only one company, Ciena is based in the United States. The router/switch subsector is dominated by five companies: Cisco, Alcatel-Lucent, Huawei, Juniper, and ZTE. Of these, Cisco and Juniper are U.S. companies with a significant share. The wireless equipment market is dominated by non-U.S. companies (Ericsson, Huawei, Nokia-Siemens, and Alcatel-Lucent), and analysts suggest that further consolidation may be anticipated, possibly resulting in a third, strong network equipment provider on par with Huawei and Ericsson or a strategic partnerships between the two smaller companies.

LTE and Move to All-IP Networks

The rapid growth of fourth-generation wireless networks using LTE has resulted from the growing use of smart devices and increasing consumer demand for data. With the on-demand connectivity of mobile phones, users are able to send data, stream videos, and post photos from anywhere around the globe as long as there is connectivity. LTE, a fourth-generation wireless standard, has achieved significant growth since its introduction by carriers in 2009 and broke the 100-million subscriber mark in 2013, taking a much shorter time than the previous two generations (2G and 3G), which faced long delays and supply issues that resulted in a slow 6- to 10-year timeframes before each hit the 100-million subscriber mark.

The infrastructure upgrade to 4G LTE requires fundamental changes to the network architecture, with the major differences being less components and an all-IP-based packet switching system model rather than relying on a circuit-switching model with an additional packet-switching technology overlay (see Figure A-2). This introduction of an IP-based system allows for greater flexibility and efficiency in the back-end processing (e.g., the Evolved Packet Core (EPC) environment) and lower end-to-end latency. To provide support for voice calls, telecommunications companies are using an IP Multimedia Subsystem (IMS) network to enable voice over LTE (VoLTE). Other emerging approaches to handle voice include circuit-switched fallback (CSFB) and simultaneous voice and LTE (SVLTE). The result is increased market demand for suppliers of LTE equipment and an opportunity for new suppliers to support the IP-based equipment.



Source: LTE Traffic Flow inside IP Backbone, http://awanetwork.blogspot.com/2013/07/lte-traffic-flow-inside-ip-backbone.html, July 24, 2013.

Figure A-2. LTE Extended Packet Core (EPC) Architecture

The requirements of LTE technology—high bandwidth, high network utilization, more symmetrical bandwidth needs—are expected to drive significant changes in the backhaul network connecting wireless base stations to the optical core network. Trends in the wireless sector include a distinct shift toward fiber connections to the tower, the increased use of small cell networks, and offloading of the cellular traffic to the small cells or to WiFi hotspots due to the scarcity of the wireless spectrum. New architectures in LTE wireless backhaul as shown in Figure A-2 will likely represent opportunities for new suppliers with innovative solutions.

Increased Adoption of Cloud Computing

Seeking new business models and sources of revenue, traditional telecommunications providers are moving into building cloud computing data centers connected to their networks or providing CDN services by embedding hardware (storage) equipment at the edges of their network, essentially distributing content toward the edge of the access network for faster and better quality services. Having the advantage of controlling the transport infrastructure and the customer base, the telecommunications operators can do more in this market but will have to add on Platform-as-a-Service (PaaS), Software-as-a-Service (SaaS), and Infrastructure-as-a-Service (IaaS) capabilities on top of their transport infrastructure offerings.

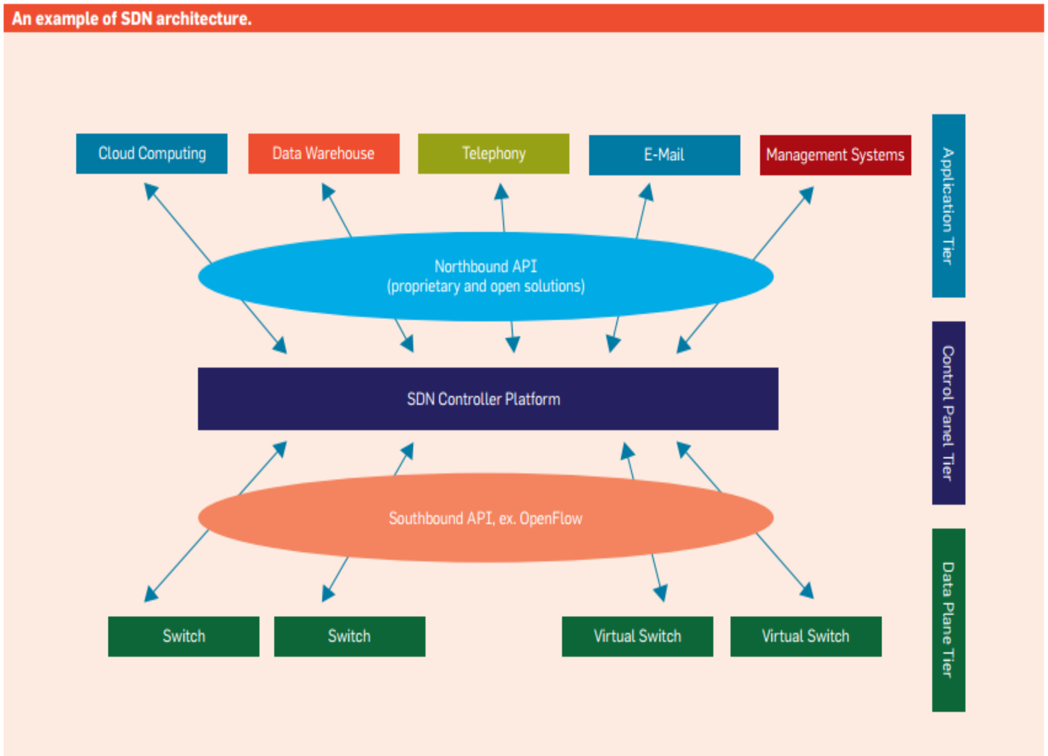
Telecommunications operators will compete with traditional cloud providers and with non-traditional providers (e.g., content providers such as Google and Amazon) who are building out high-speed networks optimized for cloud operations. Content providers, content distributers, and cloud computing vendors bring software and data center networking expertise that allows them to introduce disruptive technologies to the core and metro networks.

As a result of telecommunications providers moving into the cloud and of non-traditional and cloud providers building out high-speed networks, there will be a growing importance in the role of data centers in the telecommunications infrastructure. The increase in the number and size of data centers will impact the core/metro networks by requiring increased capacity and resulting in different traffic patterns. The pattern of traffic over the core will be more concentrated to/from the data centers—another cause for the increase in metro-level traffic vs. core traffic, depending on the geographic spread of the data centers and the applications. Moreover, the amount of backhaul traffic over metro/core should steadily increase (due to wireless demand), and there will likely be a steady increase in the need for advanced metro capacity.

Software-Defined Networking (SDN)

Networking technology is undergoing gradual but fundamental changes as content providers are becoming large consumers of networking equipment, comparable to the telecommunication providers. However, instead of using traditional networking technology based on proprietary black-box routers, cloud providers are redesigning networking architecture for cloud-based operations, with centralized network control that can be implemented via standard server software technology on commodity server hardware, an approach known as software defined networking (or SDN).

SDN is a promising new communication network architecture that provides a logically simplified network design through separation of the control and data plane and open interfaces to network functions. The architecture, shown in Figure A-3 has three layers: the **Network Apps & Orchestration,** the **Controller Platform**, and the **Physical & Virtual Network Devices**. At the bottom layer, network devices like routers and switches are controlled in real time by a middle layer SDN controller through a "southbound" protocol like OpenFlow.[26] At the top layer, applications interact with the SDN controller via a "northbound" protocol (e.g., the open Quantum Application Program Interface (API)[27]) that allows multiple applications to dynamically reconfigure networks to establish virtual networks using the SDN controller to mediate the changes.



Source: Keith Kirkpatrick. "Software Defined Networking." *Communications of the ACM* 56 (9, 2013): 16–19.

Figure A-3. SDN Architecture

The inclusion of APIs into the SDN controller has led to the concept of Network Function Virtualization (NFV), which has come from the realization that the power of standard computing servers is sufficient to implement network functions in software in real time. Functions such as routing, load balancing, security functions (firewalls, intrusion detection, and so forth) are being

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[26] Open Networking Foundation website, *Open Networking Foundation*, https://www.opennetworking.org/.

[27] The OpenStack Open Source Cloud Mission website, *Neutron/APIv2-specification*, https://wiki.openstack.org/wiki/Quantum/APIv2-specification.

implemented in the controller and provided as virtual functions as needed to applications. These functions can be offered to customers through a Network-as-a-Service (NaaS) business, allowing customers to mix and match as needed.

SDN is architected for serving data centers, and, as the role of data centers grows in the computing and communications infrastructure writ large, it will provide an impetus for the growth in adoption of SDN in larger network applications.

Demand: Large data center operators and content providers, such as Google, have pioneered the use of SDN in response to their own needs, both within their data centers and for their wide area inter-data center communications.[28] Companies such as Google, Amazon, Microsoft, and Facebook run large cloud-based data centers that have throughput needs as high (or higher) than core and metro networks. The cloud companies have been building out their own networks to meet their fast-growing needs, and both Google and Facebook have announced versions of data center and long-haul core networks. Traffic within the data centers typically exceeds the traffic carried into their data centers and is being efficiently handled by operational SDN-based systems.

Market**:** The SDN market was reported to be $360 million in 2013 and growing to $3.7 billion in 2016 (IDC). Its growth rate is expected to be similar to the server virtualization uptake.

Non-traditional networking companies, such as Google, have announced successful deployment of worldwide backbone networks using SDN technology. Google has also implemented a network virtualization service (i.e., an NaaS), called Andromeda, which is now available to its cloud-based "Google Compute" commercial offerings. Facebook recently announced that it has been using a white-box switch technology with a commodity server running the Linux operating system in its data centers and is prepared to open the design of the switch as part of its Open Compute activity.

The traditional routing companies are also moving into this domain and have acquired many of the leading smaller start-ups. The main players in the SDN market at this time are as follows:

- Big Switch (Intel invested),
- Arista,
- Cyan,
- Nuage Network (Alcatel/Lucent acquired),
- Cisco One effort, Insieme,
- Nicera (VMWare acquired),

[28] Jim Wanderer, "Case Study: The Google SDN WAN," *Computing Magazine*, January 11, 2013.

- Contrail Networks, OpenContrail project (Juniper acquired),
- Vyatta (Brocade acquired),
- Hewlett Packard, and
- LineRate Systems (F5 acquired).

In addition, traditional telecommunications providers are moving into building cloud data centers off of their networks as they seek new business models and sources of revenue. Having the advantage of controlling the infrastructure, the telecommunications operators will have to add PaaS and SaaS capabilities on top of their IaaS offerings. As a result of telecommunications providers moving into the cloud and of content and cloud providers building out high-speed networks, there will be a growing importance in the role of data centers in the telecommunications infrastructure, which may create increasing opportunities for SDN-based products.

Standards: Standards and open-source development projects are also providing momentum to this trend. The Open Network Foundation is supporting the OpenFlow standard, and many switches that support OpenFlow are on the market. The OpenFlow version 1.4 specifications include interfaces to optical ports of interest to optical network equipment suppliers.[29] Open source projects such as OpenDaylight have released code to implement controllers and defined APIs for several network functions.[30]

Most of the major routing companies as well as the important newer players are involved in the OpenDaylight project and include ConteXtream, Plexxi, Ciena, Cisco, Juniper, Brocade, Huawei, IBM, Microsoft, and others.

Opportunities**:** The potential disruptive impact of SDN technology comes from the use of standard, low-cost commodity hardware as opposed to the large, specialized network routing and switching equipment currently found in wide area networks (WANs). SDN enables the uncoupling of router hardware and software, leading to a commodity hardware-based network as a substrate that can be externally programmed and configured. This capability vastly increases the efficiency of the network. Google’s SDN-based world-wide network is reported to carry more data than Level 3’s core backbone network, making it the third largest backbone in the world. They are able to run their network at utilizations above 90% as compared with 30%–40% typically achieved in traditional networks.

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[29] Open Networking Foundation website, “OpenFlow Switch Specification Version 1.4.0: Wire Protocol 0×05,” October 14, 2013, accessed October 28, 2014, https://www.opennetworking.org/images/stories/downloads/sdn-resources/onf-specifications/openflow/openflow-spec-v1.4.0.pdf/.

[30] Open Daylight website, “Open Daylight: Technical Overview,” accessed October 28, 2014, http://www.opendaylight.org/project/technical-overview/.

Another benefit of SDN is the increased degree of automation that can be embedded in the system, which greatly reduces operational costs while increasing capacity. This capability is based on the techniques developed for efficient operation of large-scale server farms that require minimum manual intervention.

This SDN trend is becoming widely accepted, even by the traditional carriers. The Domain 2.0 white paper by AT&T acknowledges the advantages of SDN and suggests that using the model of cloud services for their network services will be the architecture of the future.[31]

While the SDN trend may possibly cause the collapse of one or more of the traditional router companies as the market for large, special-purpose routers decreases substantially, it will also lower the barriers to entry to the network routing and network maintenance market for data center networking, campus area networks, and, soon, wide-area backbone networks. Standardizing the control and data functions of the network will not only provide efficiency gains at a system level, but will also decouple vertically integrated technologies, creating opportunities for new companies. Major opportunities are anticipated for newer companies to offer innovative networking products based on software functions. U.S. companies may be well positioned to advance their market positions given the general ability of U.S. companies to rapidly innovate in the software domain.

***Barriers to entry and adoption*:** A substantial installed base of equipment with well-established suppliers in the router/switch market impacts adoption of SDN. The SDN market has been slow to develop, and adoption is still limited. This situation may be due to the reluctance of carriers to deploy a new technology with non-established suppliers and the lack of a test-bed to validate and hasten deployment.

Threats: SDN is a threat to the leading routing equipment suppliers, such as Cisco, Juniper, and Huawei, whose routers are expensive, require specialized application-specific integrated circuits (ASICs) and memories, employ proprietary operating systems, and require a large staff of expert administrators to operate and maintain. In a recent assessment of Cisco, Credit Suisse noted that "*SDN, by allowing software to be separate from the physical infrastructure, will allow competition at multiple points in the network, which was not previously possible. While the impact will take time, the threat will be very real, shrinking gross profit dollars for the industry.*"[32] Credit Suisse further noted that in the industry, "*SDN has the potential to shrink gross profit dollars available to vendors by as much as 70%*."

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[31] AT&T, *AT&T Domain 2.0 Vision White Paper*, November 13, 2013.

[32] Credit Suisse, "Cisco Systems Inc.," 18 September 2013, https://doc.research-and-analytics.csfb.com/docView?language=ENG&source=emfromsendlink&format=PDF&document_id=1022661491&extdocid=1022661491_1_eng_pdf&serialid=PD1HFGb40xKnNNhFjwLjBWR6KF1T4gy2NxpNuZwccZw%3d.

All-Optical Networking Technology

Implementing all-optical networks has long been an approach to satisfying increased throughput requirements in core and metro networks. The concept of all-optical networking was first proposed in the early 1990s where the goal was to maintain the end-to-end communications in the optical domain, eliminating the electronics.[33]

The first all-optical systems were deployed in early 2000s with the introduction of optical add/drop multiplexors (OADMs), which could switch a limited number of wavelengths between fibers in a wavelength division multiplexing (WDM) system. As these systems were deployed, practical considerations caused the focus to shift from all-optical to mixed electrical-optical (EO) systems due to limitations in the optical reach and impairments in the fiber. In addition, some functions, such as grooming (e.g., packing of data) and routing are better suited to electronics.

The transition from 10 Gbps to 100 Gbps per wavelength dense wave division multiplexing (DWDM) systems is currently underway for the commercial core and metro networks and rates of up to 12 Tbps per fiber are realizable. The expectation is that 400 Gbps and 1 Tbps per wavelength will be available commercially in the next few years, using coherent transmission and extensions to current modulation techniques, following evolutionary developments in the all-optical and the EO domains. Although there may be fundamental challenges in implementing the 1 Tbps per wave transmission capability, most of the major companies are continuing to invest in R&D along these lines and will most likely solve these problems and field products at approximately the same time.

Technological advances have continued to shift the balance back and forth between all-optical and mixed EO systems. On the optical side, researchers are advancing the flexibility of reconfigurable optical add drop multiplexors (ROADMs), increasing the size of cross-connecting switches, and improving the distance between optical signal repeaters. On the electronic side, developments such as Photonic Integrated Circuits (PICs) and silicon photonics that integrate optical components and electronics on the same chip greatly reduce the cost, size, and power burden of electronics.

PICs, introduced commercially by Infinera,[34] directly use indium-phosphide-based chips to monolithically integrate the optical and electrical functions. PICs are being used to implement high-speed optical-to-electrical-to-optical (OEO) conversions in transmission equipment but are making progress toward scaling to very large switches.

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[33] Adel Saleh and Jane Simmons, "All-Optical Networking—Evolution, Benefits, Challenges, and Future Vision," *Proceedings of the IEEE* 100, no. 5 (May 2012): 1105–1117.

[34] Infinera, *Photonic Integrated Circuits: A Technology and Application Primer,* Document Number: DS-008-001/0605 (Infinera Corporation, 2005).

Silicon photonics[35] uses common complementary metal-oxide-semiconductor (CMOS) chip manufacturing processes to integrate optical components onto a chip. Silicon photonic circuits are very cost effective for short distance, low-power applications, and R&D in this area is being pursued by large companies, such as IBM and Intel, and several major universities, such as University of California, Santa Barbara and Cornell.

All-optical networks, in general, are more difficult to configure and operate then electronic-based networks due to limitations such as a path set-up times and regeneration requirements. However, advances in network management software are reducing the configuration times required and making the networks more dynamic and remotely configurable.

Demand drivers**:** Demand for scale-up and increased capacity in core and metro networks is driving advances in optical networking. According to the Cisco Visual Networking Index,[36] annual global IP Internet traffic will surpass the zettabyte (10^{21} or 1,000 exabytes) threshold in 2016 and will reach 1.1 zettabytes per year or 91.3 exabytes (one billion gigabytes) per month in 2016. By 2018, global IP traffic will reach 1.6 zettabytes per year, or 131.6 exabytes per month. IP traffic will grow at a CAGR of 21% from 2013 to 2018.

A related driver for advances in optical networking is the growth in inter-data center communications driven by the increased adoption of cloud computing and the increasing use of fiber-based communications for the wireless backhaul. Today, U.S. carriers and service providers like Amazon and Google are transitioning from 10 Gbps to optical 100 Gbps platforms, creating opportunities for leading optical U.S. vendors such as Ciena, as well as foreign competitors. Over the next 5 years, there is an anticipated demand for technologies to support 1-terabit systems.

At the same time, the trend is for optical components to be used for shorter and shorter distances, such as for local area networks (LANs), rack-to-rack communications, inter-board, inter-chip, and eventually for on-chip communication, due primarily due to cost, power, and capacity advantages of highly integrated optical-electronic devices (e.g., PICS and silicon photonics).

Investment in R&D: Several areas of ongoing research are driving the optical and the electrical implementations. Some areas of interest in the optical domain include all-optical grooming capability (e.g., matching rates between Ethernet and packet optical system), gridless systems that can operate on variable bandwidths, better optical amplifiers for regeneration,

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[35] Winnie N. Ye and Yule Xiong, "Topical Review: Review of Silicon Photonics: History and Recent Advances," *Journal of Modern Optics* 60 (16, 2013): 1299–1320.

[36] Cisco website, "*Cisco Visual Networking Index, Forecast and Methodology, 2013–2018*," accessed October 28, 2014, June 10, 2014, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html.

advanced modulation techniques, real-time performance monitoring, and advances in multi-core or multi-mode fibers. Software for automated management of optical networks is continuing to reduce the time needed to set up optical networks and to recover from faults. Further advances in PICs or silicon photonics will continue to drive down the costs of the components and increase the functionality of the EO systems.

Market consideration**:** There is continuing growth in the optical network market and slowly growing demand for optical transport equipment from the traditional suppliers. AT&T is rolling out a new high-speed network to 100 cities, known as "U-Verse with GigaPower." The AT&T network will provide 1 Gbps to the premise but uses their existing local infrastructure. This decision is probably being made in response to Google's high-speed fiber network, "Google Fiber," which is being deployed to selected cities. Verizon, on the other hand, has slowed its fiber-to-the-home deployment and will increase the use of wireless broadband for access in rural or low-density areas.

The larger router/switch companies are attempting to vertically integrate by adding optical transmission equipment to their routers to capture some of the optical transport market. Similarly, the optical transport vendors are trying to add routing and switching capabilities to their transport equipment. There is also a distinct shift toward the use of fiber as the backbone connection to the cellular base station, which will benefit the optical communications equipment supplier segment dominated by companies such as Oclaro, Finisar, and JDS Uniphase.

Opportunities: Transitioning U.S. content/service providers such as Google and Amazon from 10 Gbps to 100 Gbps to 1-terabit platforms creates opportunities for vendors such as Ciena or Infinera, which has been at the cutting edge of the transition to 100 Gbps, giving the United States an advantage.

In addition, improvements and cost lowering in silicon photonics and PIC technologies are being sought to realize the goals of optoelectronic technology all the way down to on-chip communications.

A recent workshop held by the National Science Foundation (NSF) on *Scaling Terabit Networks: Breaking Through Capacity Barriers and Lowering Cost with New Architectures and Technologies*[37] was focused on coming changes to optical networking that will be needed to meet the demands of cloud computing, big data analytics, and other trends such as M2M communications of the IoT. The authors claim that evolutionary advances will not be enough to meet the demand. A cross-disciplinary approach is needed. The report called for research into

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[37] Karen Bergman, Vincent Chan, Daniel Kilper, Inder Monga, George Porter, and Kristin Rauschenbach, *Scaling Terabit Networks: Breaking through Capacity Barriers and Lowering Cost with New Architectures and Technologies*, Report on Workshop held on 19–20 September 2013, Washington, DC.

programmable, virtualized, and intelligent optical networks to support more dynamic, cognitive, and autonomic control, adaptive security, and new levels of optimization. This call for research is clearly influenced by the success of SDN in the data centers. In addition, the report promotes green-field designs and the increased use of parallelism in the optical networks.

The workshop report calls for increased support for greater access to silicon photonic foundries, maturation of PIC technologies for production of new components, and collaborative, multi-user testbeds for optical terabit-scale experiments needed to maintain the U.S. advantage in optical networks. In addition, there may be advantages of optical networks from the security perspective; however, additional R&D is needed to verify this claim.

Barriers to entry and adoption*:* The market-penetration attempts of the transport market by the larger routing companies and of the routing market by transport vendors will likely saturate those markets. The market will likely not be able to support all of these companies, and some consolidation will occur.

The traditional carriers that dominate this space are also reluctant to radically shift the technologies they use in their core and metro networks. This approach has worked to the disadvantage of a company such as Infinera, which has developed advanced products based on PIC technology but has seen slow adoption rates. Smaller companies will have difficulties breaking into this domain.

Wireless 5G and Small Cell Technology

The success of 4G cellular technology, primarily LTE, in the United States and globally has resulted in huge investments in the necessary infrastructure. However, the largest system-level suppliers are non-U.S. companies, and U.S. companies are not likely to be able to penetrate this market in the near term. This situation has led to the hypothesis that opportunities may arise in the deployment of the next generation of cellular networks, 5G. No consensus has yet been reached on what constitutes 5G networks, but it appears to promise faster speeds (e.g., download a 1-hour high definition (HD) video in 6 seconds), increased spectral efficiency, support for the IoT (i.e., multiple types of devices (e.g., wearable sensors, machine-to-machine communications)), always on and connected capability, and a seamless integration of communications, processing and storage.[38] 5G will rely on new technologies, such as small cells or heterogeneous networks (Hetnets), cognitive radios, mesh networking, smart antennas (beamforming), and many others. U.S. companies may be able to “leapfrog” to the next generation through innovative products, regain market share, and create barriers of entry for foreign companies.

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[38] Lisa Eadicicco, “If You Think 5G Is All about Faster Network Speeds, You’re Wrong,” *Business Insider* (July 26, 2014)

The current deployments of 4G LTE are based on the 3GPP standard versions 8 (2008) and 9 (2009). The next version, LTE-Advanced (LTE-A), which has been under development for several years, represents a major enhancement to LTE and was functionally frozen in April 2011 with 3GPP release 10. LTE-A allows for peak rates of 3.3 Gbps (downlink) using multiple input multiple output (MIMO) technology. Given this high bandwidth requirement, high network utilization, and more symmetrical bandwidth needs, the wireless backhaul network will require significant changes and upgrades. Some of the other key concepts that are being implemented in LTE-A include carrier aggregation, relay nodes, self-organization, and Hetnets of small cells. Release 11 (December 2012) provides further support for Hetnets and small cells, internal coexistence (with WiFi, Bluetoooth, and so forth), and coordinated multi-point operation (between base stations). Releases 12 and 13, are focused on handoff in small cells and are still under development. Carrier aggregation, another technique in which radios can operate in multiple, non-contiguous frequency bands to achieve higher capacity, is still under discussion and development.

One of the serious challenges for wireless system deployment, in general, is the availability of spectrum. At the current time, spectrum that is desirable for cellular telephony use is scarce and expensive and is allocated (by licenses) exclusively to carriers via an auction mechanism that sometimes restricts the ability of smaller companies to participate. One consequence of exclusive licensing is that spectrum bands are often idle for a large percentage of time. Various technologies are being proposed that can dynamically share spectrum bands among users to make use of this idle time and increase spectral efficiency. Cognitive radios are designed to operate on a range of frequency bands and can intelligently switch between these bands to increase the efficient use of the available spectrum. Cognitive radios rely on software-defined radio technology in which a significant portion of the functions of a radio is moved from their traditional implementation in hardware to software-based implementations. This change is providing opportunities for U.S. and foreign software development companies to offer innovative products.

Another technique to increase the efficient use of the spectrum is to employ Hetnets, or small cells, that operate within larger cells, using novel techniques to ensure that the smaller or micro-cells do not cause interference to the larger macro cells. Cellular carriers have deployed versions of small-cell technologies as pico-cells or femto-cells, depending on the radio range and the number of customers that they can handle. Small cells can operate on higher frequencies over shorter distances and greatly increase the overall wireless capacity in a geographic area. Offloading the cellular traffic to WiFi networks represents a similar technique that relies on unlicensed spectrum rather than purchased spectrum. In both cases, the small cells are assumed to be locally connected to the wired networks for coordination and for moving traffic between networks. This will continue to contribute to the loading of the metro area networks as the use of small cells increases.

International efforts to define 5G technology are underway and significant activities have been initiated in Europe and Asia. To date, U.S. efforts in the area are limited. According to a recent report,[39] *"North America, in particular the United States, has long been leading the global efforts in the advancements of mobile technologies all the way from analog through 4G. In order to continue their deployment leadership, the U.S. needs to remain a strong player in the vision, definition and development of 5G by accommodating it to the unique marketplace in North America. Public and private investment in research and development (R&D) for 5G must increase significantly immediately to ensure that it develops optimally."*

Demand: The increase in use of smart phones and the other wireless devices is driving the huge increase in the data capacity needs of wireless systems. Again, video traffic is a large component of this increase. There is a concern that there will be a spectrum shortage if the current technology evolution is not changed, since the available spectrum in the desired frequency bands becomes more difficult to obtain.

Markets**:** The 4G wireless market was expected to be about $15.8 billion in 2014 and growing to $17.8 billion in 2016 and then dropping back to $15.1 billion in 2017. Its average growth rate since 2011 is expected to remain about 13.4%.[40]

Standards: LTE-A standards are evolving rapidly and are providing a strong impetus for advanced development efforts since there is high likelihood products can be deployed in systems from multiple vendors. New 5G standards are still in the early formative stage.

Current policy actions**:** The government is already taking some policy actions to facilitate aspects of 5G. In particular, the Federal Communications Commission (FCC) has asked for comments on a scheme to allow for advanced spectrum sharing and small cells in the 3.5-GHz band[41] following the recommendations of the President's Council of Advisors on Science and Technology (PCAST) report on spectrum.[42] In addition, the FCC and National Telecommunications and Information Administration (NTIA) have asked for comments on a proposed Model City that would serve as a test-bed for spectrum-sharing technologies in a realistic environment.[43]

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[39] 4G Americas, "4G Americas' Summary of Global 5G Initiatives," June 2014.

[40] Infonetics Research, *Infonetics: Mobile Infrastructure Market Declines, while Mobile M2M Spending Was Up 25% Year-over-Year* (June 2013).

[41] FCC, "In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550–3650 MHz Band, Further Notice of Proposed Rulemaking," GN Docket No. 12-354, FCC 14-49, April, 23, 2014.

[42] PCAST, "Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth," Presidential Council of Scientific Advisors (PCAST), Report to the President, July 2012.

[43] FCC and NTIA, "Model City for Demonstrating and Valuating Advanced Sharing Technologies, Public Notice," ET Docket No. 14-99, DA 14-981, July 11, 2014.

Opportunities: While companies like Cisco are well positioned in the local area network domain, newer innovators such as Ruckus Wireless or Artemis could become competitive forces in the backhaul and small-cell domain. Intel is well positioned in the IoT, which encompasses M2M and machine-to-Internet communications for masses of devices. The need for IoT products in this space in the coming years will represent ample opportunities for new companies. In addition, opportunities exist for software development efforts in cognitive radio and associated services for which U.S. companies may be able to offer innovative solutions.

Intel has been a leader in the championing of the IoT, but a question still remains whether it will be able to capitalize on this technology in terms of market-leading products since desired standards are still under development.

Qualcomm is a leader in advanced wireless technologies and should be able to play a leading role in 5G definition and development. However, in the spectrum-sharing arena, Qualcomm is supporting a European approach rather than the approach being followed in the current FCC 3.5-GHz efforts.

Barriers to entry and adoption: The use of cognitive radios and spectrum-sharing technologies are still at an immature stage. There is regulatory uncertainty about policies and rules and a strong criticism of shared licensing concepts from the carrier side. Different users of the radio spectrum, such as military systems, are reluctant to agree to share their spectrum allocations due to the uncertainty about whether the sharing techniques can operate with systems that have vastly different operating characteristics. There is also a lack of commercial products in the cognitive radio area due to these factors. More research, development, and testing are needed to prove the technologies.

Mesh networking has been trialed in several attempts but has not taken hold in the commercial arena, primarily since WiFi hotspots have been so successful in the home and the small business domains.

Deploying the wireless infrastructure needed for a new generation of wireless technology is very expensive. For example, in 2012, AT&T spent $14 billion on LTE over 3 years.

Threats: Foreign companies are already moving to establish a lead in 5G technologies. South Korea and the EU have announced an agreement to cooperate on 5G definition, frequencies and standards.[44] South Korea will invest about $1.6 billion in a joint public-private effort. The EU has

[44] Frances Robinson and Min-Jeong Lee, "EU, South Korea to Ally on Faster Mobile Access," *Wall Street Journal*, June 16, 2014.

pledged about $1 billion, and its industry partners have pledged more than $4.5 billion into 5G research. Huawei has announced a $600 million investment in a 5G research program.

In the United States, there appears to be relatively limited research activities aimed at 5G development.[45] Most of the research, such as that funded by the NSF, is aimed at developing longer term basic technologies rather than advancing the more likely 5G scenarios. The level of activity in the United States is much less than what is being done internationally.

[45] 4G Americas, "4G Americas' Summary of Global 5G Initiatives," June 2014.

Appendix B.
Policy Options

A collection of classes of policy options that are applicable to the three telecommunications subsectors of interest are identified. Each class of policy option is described in terms of more specific policy actions that can be used by government officials. Table B-1 summarizes policy classes and policy actions.

Table B-1. Policy Classes and Policy Actions

Policy Classes	Policy Actions
Investments in research and development (R&D)	Grants, Small Business Innovation Research (SBIR)
Investment in cooperative agreements	Collaborative research and production
Technology transition	Support for scale-up of applied research, Proof of Concept centers and test-beds
Investment in production	Government as early adopter, Guaranteed purchases, Defense Production Act (DPA) Title III, National Network for Manufacturing Innovation (NNMI)
Financing	Loans, loan guarantees, credits, financing
Trade	Agreements, treaties, enforcement, tariffs
Regulation	Industry-specific regulation, export control, the Committee on Foreign Investment in the United States (CFIUS)
Standards	Government participation/support, requirements to use
Tax	Federal, state, and local tax incentives

Each of these classes will be described, however, in our analysis process of the subsectors, some of the classes were not selected as viable options.

Investments in R&D

Investments are areas where public funding[46] is made available to academic and industrial partners to be used to enhance technological and market competitiveness. R&D has been a traditional area in which public funds have been used to spur innovation, and, historically, many of the telecommunications technological breakthroughs came about because of U.S. Government R&D investment.[47] Significant public funding (primarily Federal) is provided through the Department of Defense (DOD), the Department of Energy (DOE), and the National Science Foundation (NSF) for R&D in telecommunications-related areas. These grants and contracts with universities and industry fund and provide incentives for important breakthrough R&D. In addition to these investments, the Federal Government runs a substantial SBIR program that allocates certain percentages of overall Federal spending to startups and small business to fund and incentivize them. DOD also has a number of programs that provide other forms of R&D investment, including the ManTech program, which funds manufacturing R&D aimed at lowering costs and improving productivity. DOD also runs a number of focused laboratory efforts through grants to universities and industry.

Cooperative Research and Production

The establishment of globally competitive capabilities requires the close cooperation of industry and academia. The development of close public-private partnerships is vital to enabling public investments in R&D to become successful in the market. Cooperative Research and Development Agreements (CRADAs) are an important way for government to enter into cooperative research with industry and academia. In addition, the government has a long history of establishing public-private partnerships, not only for research with academia, but also with industry. NSF has a successful Industry/University Cooperative Research Program (I/UCRC) that supports joint research. Under the National Cooperative Research and Production Act (NCRPA) of 1993 the government has pursued a range of public-private partnerships with industry and academia, including the very successful Sematech. It may be possible to create a new public-private partnership through these same models or perhaps create a new National Institute of Standards and Technology (NIST) Center of Excellence for the telecommunication sector.

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[46] We use the term "public funding" to refer to funding that comes from Federal, State, or local sources.

[47] An example of a key innovation is the Internet, which resulted from work by the Defense Advanced Research Projects Agency (DARPA) on what at the time was called the Advanced Research Projects Agency Network (ARPANET).

Technology Transition

Once innovations have been made, significant challenges still remain in transitioning research results into successful capabilities and products. Several programs are aimed at transition, such as the Federal Government-wide Small Business Technology Transfer (STTR) program, which helps transfer technologies into industry and supports the development of new industrial capabilities. The STTR, together with the SBIR, fund over $2.8 billion in overall grants and awards each year. Another example was the NIST Advanced Technology Program (ATP), which later became the Technology Innovation Program (TIP) but is no longer active.

Government Investment in Production

The government can use its buying power to invest in a company's product in several ways. The government can become an early adopter of the product by purchasing a sufficient quantity at a stage where the product has not yet garnered a sustaining level of sales. The government can also provide a guaranteed level of purchase that can sustain an existing company while it responds to a changing market condition. These options are somewhat limited by the fact that the government-related sales in the telecommunications sector is a small fraction of the total market.

DOD runs the DPA Title III program,[48] which helps achieve and maintain domestic industrial capabilities of national security interest by making important investments and, in particular, guaranteeing markets, thereby reducing risks associated with companies capitalizing their enhanced and more cost competitive capabilities.

Tax incentives

The costs of business can be greatly affected by the tax burdens. In the global landscape, tax incentives have made an important difference in the global competitiveness of U.S. companies. In important telecommunications segments, domestic companies may be at a competitive tax disadvantage. Important areas for tax incentives include Federal, state, and local tax incentives, investment tax credits, lowered corporate rates, R&D tax credits, real estate tax abatements, and sales tax exemptions. It is important to note that state level tax incentives have played an important role in affecting outcomes that reduce costs of doing business.

Financing

An underappreciated aspect of competitiveness is the ease and cost of financing for companies. In the global market, the ease and cost of financing has ended up being an important

[48] Jared T. Brown and Daniel H. Else, "The Defense Production Act of 1950: History, Authorities, and Reauthorization," Congressional Research Service, July 30, 2014.

competitive advantage. Some global companies have been able to obtain significant financing for export credits, enabling them to offer much more cost competitive offers into emerging markets. Important policy options would include loan and credit programs and loan guarantee programs.

Standards Activities

Another underappreciated area that can dramatically affect the market is the role of standards. Standards can play an important role in influencing the markets to allow interoperation and thus keep competition strong by reducing vertical integration. Standards can also be employed to protect interests by ensuring that domestic companies' capabilities and strategies are reflected in global standards that enable them to retain competitive global market opportunities. NIST has significant participation in standards efforts, and it (and other government agencies) could increase its efforts in the telecommunications area. It is also important to make sure the U.S. interests are properly reflected by cooperating with important domestic and international standards bodies such as the International Telecommunication Union (ITU), the Telecommunications Industry Association (TIA), the Internet Engineering Task Force (IETF), the International Organization for Standardization (ISO), and the Institute of Electrical and Electronics Engineers (IEEE).

Regulation

Regulation establishes laws of engagement—not only in domestic markets, but also globally. Regulation can take a myriad of forms, and there are a number of opportunities for new areas of regulation to affect outcomes. Negotiating international open access (e.g., wireless, backbone, Internet exchange points, and undersea cables) may be a way to retain a more vigorous and fair global telecommunications market. Regulating the domestic telecommunications market as a public utility (e.g., universal access, Net Neutrality) may help avoid market imbalances or create them. The use of government regulatory authority can also be used to maintain competitive markets (e.g., oppose mergers, anti-trust) such as more aggressive use of Federal Communications Commission (FCC) and Department of Justice (DOJ) reviews. Issues such as spectrum availability and restrictions on use, both domestically and internationally, remain an important mechanism for maintaining competitiveness. Finally, the issue of Internet Protocol (IP) protection remains vital. The global landscape for IP protection remains unfair, and domestic companies are at a significant disadvantage in many countries.

Trade

The final policy option considered is trade. Traditional areas such as the use of the CFIUS can be used to prevent the acquisition of domestic companies by foreign interests, but this approach is not thought to be a very effective option in this industry sector. Export control, such as that through International Traffic in Arms Regulations (ITAR) and the Commerce Control List (CCL) rules, has been a traditional way of controlling the flow of technologies and products, but telecommunications has become driven mostly by commercial interests and restricting export of telecommunications is actually somewhat detrimental to U.S. competitiveness. Lifting export controls on some aspects of telecommunications might actually benefit U.S. companies without undue harm to national security. Traditional tools of trade, such as barriers, tariffs and agreements, can be applied, but, to maintain fair and open global trade, these tools are limited. Despite continual efforts, the global competitive landscape as overseen by the World Trade Organization (WTO) remains disparate in the telecommunications sector. Substantial subsidies are provided by countries like China, and an important policy option might be to more aggressively protest to the WTO and negotiate broad agreements against these sorts of subsidies in WTO.

Illustrations

Figures

Tables

References

4G Americas, *4G Americas' Summary of Global 5G Initiatives*. June 2014. http://www.4gamericas.org/documents/2014_4GA%20Summary%20of%20Global%205G%20Initiatives_%20FINAL.pdf.

AT&T. *AT&T Domain 2.0 Vision White Paper*. November 13 2013. http://www.att.com/Common/about_us/pdf/AT&T%20Domain%202.0%20Vision%20White%20Paper.pdf.

Atkinson, Robert D. *Competitiveness, Innovation and Productivity: Clearing up the Confusion*. http://www2.itif.org/2013-competitiveness-innovation-productivity-clearing-up-confusion.pdf.

Bergman, Karen, Vincent Chan, Daniel Kilper, Inder Monga, George Porter, and Kristin Rauschenbach. *Scaling Terabit Networks: Breaking through Capacity Barriers and Lowering Cost with New Architectures and Technologies*. Report on Workshop, 19–20 September 2013, Washington, DC.

Booz and Company, *World Telecommunications Outlook*, February 20, 2013. http://www.strategyand.pwc.com/media/file/Strategyand&co_WorldTelecommunicationsOutlook2003.pdf.

Brown, Jared T., and Daniel H. Else. 2014. *The Defense Production Act of 1950: History, Authorities, and Reauthorization*. Washington, DC: Congressional Research Service, July 30, 2014.

Cisco Visual Networking Index. *Forecast and Methodology, 2013–2018.* June 10, 2014. http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html.

Defense Production Act Committee (DPAC) Telecom Working Group. *Assessing US Capabilities in the Global Telecom Equipment Market.* February 2012 (Draft).

Department of Commerce and the National Economic Council. *The Competitiveness and Innovative Capacity of the United States*. Washington, DC: Department of Commerce, January 2012. http://www.commerce.gov/sites/default/files/documents/2012/january/competes_010511_0.pdf.

Eadicicco, Lisa. "If You Think 5G Is All about Faster Network Speeds, You're Wrong." *Business Insider.* July 26, 2014. http://www.businessinsider.com/5g-network-speed-2014-7/.

Federal Communications Commission (FCC). "In the Matter of Amendment of the Commission's Rules with Regard to Commercial Operations in the 3550–3650 MHz Band, Further Notice of Proposed Rulemaking." GN Docket No. 12-354, FCC 14-49. April, 23 2014. http://www.fcc.gov/document/proposes-creation-new-citizens-broadband-radio-service-35-ghz.

Federal Communications Commission (FCC) and National Telecommunications and Information Administration (NTIA). "Model City for Demonstrating and Valuating Advanced Sharing Technologies, Public Notice." ET Docket No. 14-99, DA 14-981. July 11 2014. Accessed October 28, 2014. https://apps.fcc.gov/edocs_public/attachmatch/DA-14-981A1.pdf.

Fine, Lawrence G. *The SWOT Analysis: Using Your Strength to Overcome Weaknesses, Using Opportunities to Overcome Threats.* First edition. CreateSpace Independent Publishing Platform, October 2009.

Freeman, Christopher. *Technology and Economic Performance: Lessons from Japan.* London: Pinter, 1987.

Humphrey, Albert. "SWOT Analysis for Management Consulting." *SRI Alumni Newsletter*. SRI International, December 2005.

Infinera. *Photonic Integrated Circuits: A Technology and Application Primer*. DS-008-001/0605. 2005. http://www.infinera.com/pdfs/whitepapers/Photonic_Integrated_Circuits.pdf.

Infonetics Research. *Strong Sequential Growth for Carrier Routers and Switches in 2Q14 Masks Long-Term Trend*. August 2014. http://www.infonetics.com/pr/2014/2q14-Service-Provider-Routers-Switches-Market-Highlights.asp.

———. *Infonetics: Mobile Infrastructure Market Declines, while Mobile M2M Spending Was Up 25% Year-over-Year*. June 2013. http://community.comsoc.org/blogs/alanweissberger/infonetics-mobile-infrastructure-market-declines-while-mobile-m2m-spending-was.

———. *Infonetics & IDC: Worldwide Carrier Ethernet Switch & Router Results and Market Forecasts*. May 2013. http://community.comsoc.org/blogs/posts?page=26&sort=date&order=asc.

———. *Optical Network Hardware Quarterly Market Share, Size and Forecasts*. (February 2013). http://community.comsoc.org/blogs/alanweissberger/optical-network-market-poised-growth-2013-especially-emea-region.

———. *Infinera, Fujitsu, Cisco, Ciena, and Huawei top Infonetics' New Optical Networking Vendor Scorecard.* March 2014. http://www.infonetics.com/pr/2014/Optical-Vendor-Network-Hardware-Scorecard-Highlights.asp.

Kirkpatrick, Keith. "Software-Defined Networking." *Communications of the ACM* 56, 9 (September 2013), 16–19. doi: 10.1145/2500468.2500473.

Manyika, James, Lenny Mendonca, Jaana Remes, Stefan Dluβmann, Richard Dobbs, Kuntala Karkun, Vitaly Klintsov, et al. *How to Compete and Grow: A Sector Guide to Policy*. McKinsey & Company, March 2010.

President's Council of Advisors on Science and Technology (PCAST). *Report to the President: Realizing the Full Potential of Government-Held Spectrum to Spur Economic Growth*. Washington, D.C.: Executive Office of the President, July 2012.

Robinson, Francis, and Min-Jeong Lee. "EU, South Korea to Ally on Faster Mobile Access." *Wall Street Journal*. June 16, 2014.

Saleh, Adel, and Jane Simmons. "All-Optical Networking—Evolution, Benefits, Challenges, and Future Vision." *Proceedings of the IEEE* 100 (5): 1105–1117. 2012. doi: 10.1109/JPROC.2011.2182589.

The Advisory Committee on Measuring Innovation in the 21st Century Economy. *Innovation Measurement: Tracking the State of Innovation in the American Economy*. Washington, DC: Department of Commerce, January 2008.

Wanderer, Jim. "Case Study: The Google SDN WAN." *Computing Magazine*. January 11, 2013. http://www.computing.co.uk/ctg/analysis/2235886/case-study-the-google-sdn-wan#/.

Ye, Winnie N., and Yule Xiong. "Topical Review: Review of Silicon Photonics: History and Recent Advances," *Journal of Modern Optics* 60 (16): 1299–1320. doi:10.1080/09500340.2013.839836.

Abbreviations

ADM	add/drop multiplexor
APA	Defense Production Act
API	Application Program Interface
ARPANET	Advanced Research Projects Agency Network
ASIC	application-specific integrated circuit
ATM	Asynchronous Transfer Mode
ATP	Advanced Technology Program
BTS	base transceiver station
CAGR	compound annual growth rate
capex	capital expenditure
CCL	Commerce Control List
CDN	content delivery network
CFIUS	Committee on Foreign Investment in the United States
CMOS	complementary metal-oxide-semiconductor
CRADA	Cooperative Research and Development Agreement
CSFB	circuit-switched fallback
CWDM	coarse wave division multiplexing
DCS	digital cross-connect
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DPAC	Defense Production Act Committee
DWDM	dense wave division multiplexing
EO	electrical-optical
EPC	Evolved Packet Core
EU	European Union
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FCC	Federal Communications Commission
FTTH	Fiber to the Home
GW	gateway
HD	high definition
Hetnet	heterogeneous network
I/UCRC	Industry/University Cooperative Research Program
IaaS	Infrastructure-as-a-Service
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IMS	IP Multimedia Subsystem
IoT	Internet-of-Things
IP	Internet Protocol
ISO	International Organization for Standardization

IT	Information Technology
ITAR	International Traffic in Arms Regulations
ITU	International Telecommunication Union
LAN	local area network
LTE	Long-Term Evolution
LTE-A	LTE-Advanced
M2M	machine-to-machine
MIMO	multiple input multiple output
MME	Mobility Management Entity
MMF	multi-mode fiber
MPLS	Multiprotocol Label Switching
MSPP	Multiservice Provisioning Platform
NaaS	Network-as-a-Service
NASA	National Aeronautics and Space Administration
NCRPA	National Cooperative Research and Production Act
NFV	Network Function Virtualization
NIST	National Institute of Standards and Technology
NNMI	National Network for Manufacturing Innovation
NSF	National Science Foundation
NTIA	National Telecommunications and Information Administration
OADM	optical add-drop multiplexer
OEO	optical-to-electrical-to-optical
OSTP	Office of Science and Technology Policy
OTN	Optical Transport Network
OXC	optical cross connect
P2P	peer-to-peer
PaaS	Platform-as-a-Service
PCAST	President's Council of Advisors on Science and Technology
P-GW	Packet Data Network Gateway
PIC	Photonic Integration Circuit
PON	Passive Optical Network
R&D	research and development
ROADM	reconfigurable optical add drop multiplexor
RRH	Remote Radio Head
SaaS	Software-as-a-Service
SBIR	Small Business Innovation Research
SDH	Synchronous Digital Hierarchy
SDN	software-defined networking
S-GW	Serving Gateway
SLTE	submarine line terminating equipment
SMF	single mode fiber
SONET	Synchronous Optical Networking
STPI	Science and Technology Policy Institute
STTR	Small Business Technology Transfer

SVLTE	simultaneous voice and LTE
SWOT	Strengths, Weakness, Opportunities, Threats
TIA	Telecommunications Industry Association
TIP	Technology Innovation Program
Tpbs	terabits per second
UMTS	Universal Mobile Telecommunications System
VCSEL	vertical-cavity surface-emitting laser
VOD	video on demand
VOIP	Voice Over Internet Protocol
VOLTE	voice over LTE
VPN	virtual private network
WAN	wide area network
WDM	wavelength division multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
WTO	World Trade Organization
xDSL	broadband access technologies based on DSL technology

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14. ABSTRACT

Commercial drivers and globalization have resulted in a weakening of the domestic telecommunications equipment industry which raises concerns about economic growth and national security. This study looked at three key telecommunications equipment sectors; optical core network, router/switch, and wireless and developed a framework for supporting government decision makers in evaluating policy options. A key hypothesis is that emerging trends may reveal opportunities for policy options to be effective. The study conducted interviews to establish goals that captured the concerns throughout the Federal Government. A framework was developed using a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis to identify opportunities and then select appropriate and effective policy options. This framework was applied to each of the three key sectors and a set of findings on potential policy actions was reported. This work highlights one strategic method that can be used to identify emerging trends where policy actions may have an increased effect.

15. SUBJECT TERMS

Telecommunications, Equipment, Domestic, Federal, Policy, Optical, Router, Switch, Wireless, Strengths, Weaknesses, Opportunities, Threats, Emerging, Opportunity

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