The 5G Wireless Future:

Apps, Devices, Networks, Spectrum

Minnesota

Governor's Broadband Task Force

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Entropy Economics

5G Wireless Future

How the Internet will become the ‘Exanet’

“The Internet was not conceived to be the commercial, social, and industrial platform for the entire planet.”

5G Wireless Future

- 5G = a new network designed as foundation for much broader swath of economic activity (e.g., in the physical indsturies)
  - more capacity for smartphones, yes
  - but also to connect vehicles, machines, infrastructure, Internet of Things, and more
  - faster residential and enterprise broadband, yes
  - also huge array of connected devices with highly variable (and unknown future) needs

5G Wireless Future

- **Applications** – mobile, residential & enterprise broadband, healthcare, IoT, connected cars, drones, geolocation, industrial, scientific info gathering, retail, events, virtual/augmented reality, security, public safety…

- **Devices** – smartphones, tablets, wearable computers, vehicles, drones, smart infrastructure, machines, sensors, packages, appliances, kiosks…put a wireless computer/sensor in most objects?

- **Networks** – small cells, fiber, software defined networking, network function virtualization, heterogeneous devices/bands/sites/nodes/air interfaces (HetNets) …

- **Spectrum** – carrier aggregation, high frequency bands, licensed, unlicensed, shared, government spectrum –> commercial…

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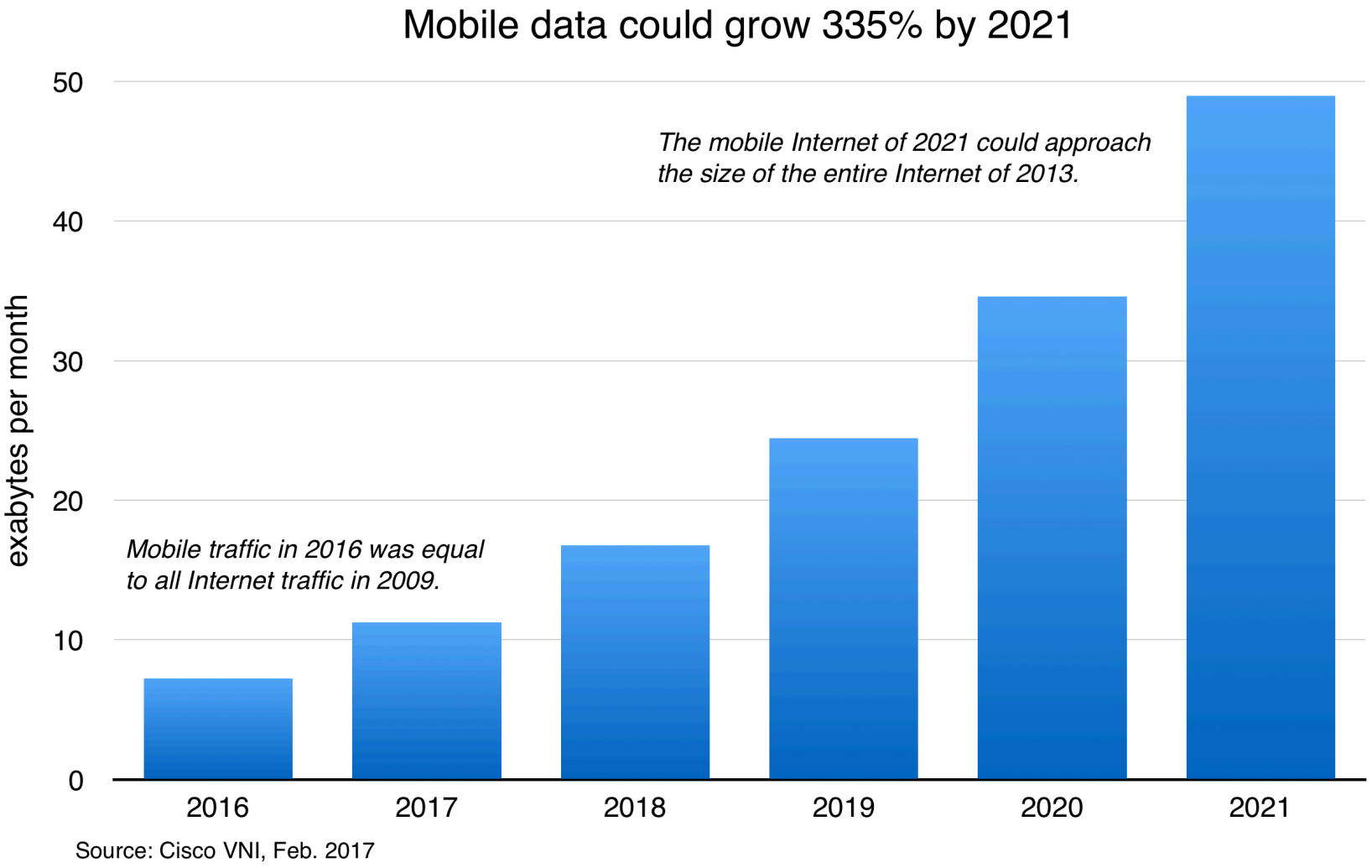

Source: Cisco VNI, Feb. 2017

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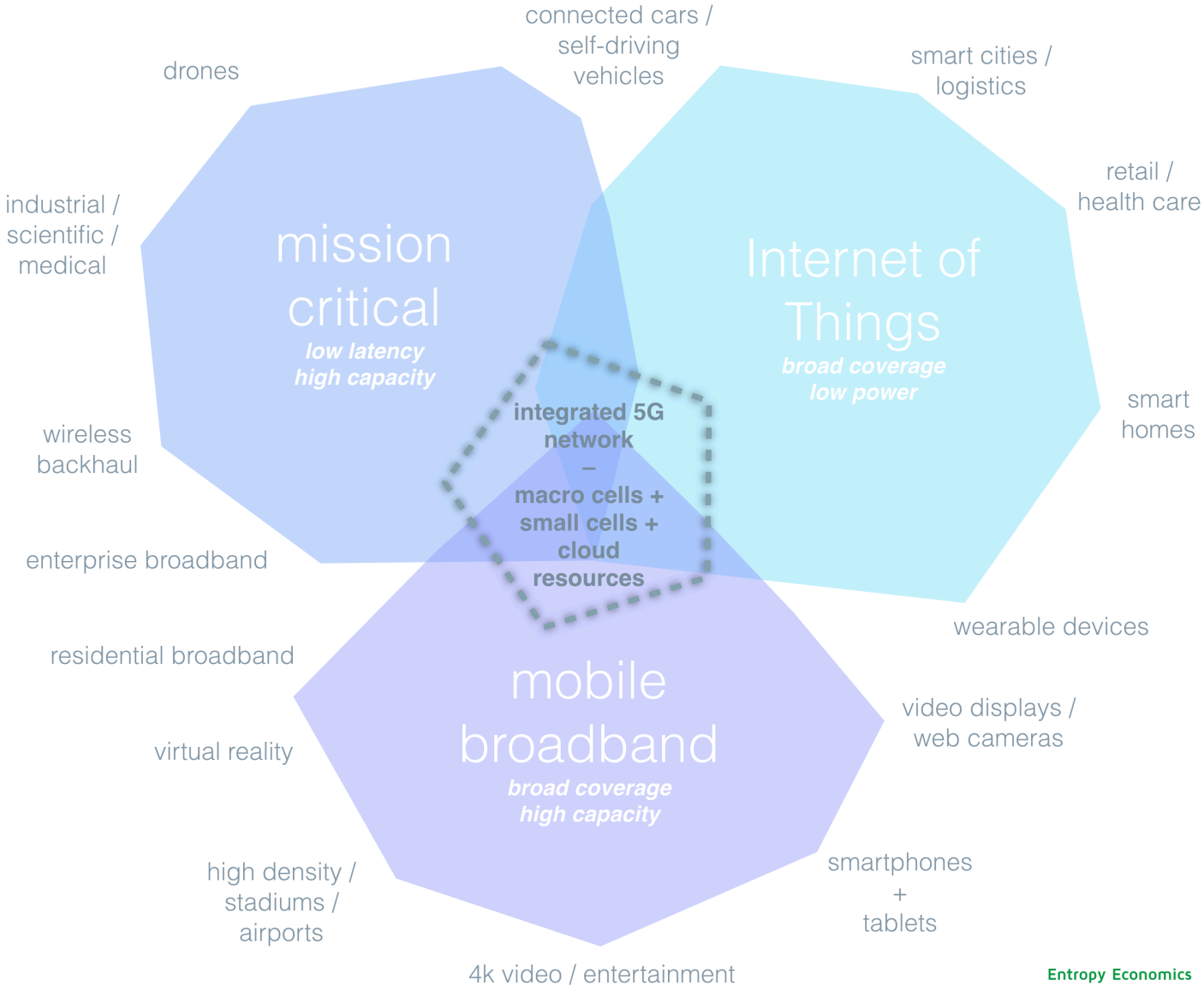
- Wireless data traffic driven by two big waves:
    - the boom in mobile video, which demands far more capacity than previous mobile applications, and is changing the ***nature*** of wireless data traffic.
    - meanwhile, the emerging Internet of Things (IoT) — what I call the immersive Internet — is driving a rapid acceleration in the ***number*** of connected devices.

5G Wireless Future



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- Video still the killer app…
  - …which will pay for the network, and provide the capabilities used for cars, IoT, etc.
  - in other words, the desire by AT&T and Verizon to compete with cable TV and broadband video – *and the desire of cable firms to compete in wireless* – will help pay for the full range of 5G 'exanet' possibilities.
  - new applications and services will open up new business models for carriers.

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- Wide array of devices, with highly variable needs
    - 4K cinema needs high throughput
    - autonomous cars/drones and industrial machines need high reliability and low latency
    - tens of billions of IoT devices need wide coverage and low power

Radio Shack, 1991
13 electronic gadgets . . .

$3,000 worth of functionality . . . all of which now contained in a smartphone!

. . . in fact, a vast underestimate

The $12-million iPhone

How much would it have cost to build an iPhone in 1991?

	cost in 1991	iPhone 5 (2014)	iPhone 7 (2016)
Nonvol. memory	$45,000 per GB	$1.44 million	$5.76 million
Computation	$30 per MIPS	$.620 million	$3.6 million
Bandwidth	$100 per Kbps	$1.5 million	$3.3 million
Total		**$3.56 million**	**$12.66 million**

* Does not include cost of software, display, camera, sensors, and numerous other components. Nor does it reflect inflation.

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- A New Network Architecture
  - densification with Small Cells
  - today ~320,000 cell towers/sites in U.S.
  - tomorrow, potentially millions of cells on lamp-posts, utility poles, buildings, neighborhoods, campuses
  - fiber optics connecting most cells
  - Software Defined Networks / Network Function Virtualization
  - using general purpose computing platforms (instead of “telecom equipment”) to move network functions to the cloud
  - estimate of ~$275 billion to build 5G networks in U.S.

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- **Evolution** – In some ways, move from 4G toward 5G will seem evolutionary:
    - LTE –> Gigabit LTE, similar air interfaces
- **Revolution** – In other ways, 5G will be bigger leap than any previous generation:
    - Small Cells + Fiber + Software Defined Networks + High Bands + More Unlicensed + Mixing Licensed & Unlicensed + serving much broader array of users

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- Lots more spectrum, including High Bands
  - Small Cells boost reuse of existing spectrum
  - Low and mid-band spectrum used for wide coverage
  - New high bands massively increase point-to-point bandwidth
  - High bands good for extreme capacity over short distances

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Spectrum: radio and fiber optic

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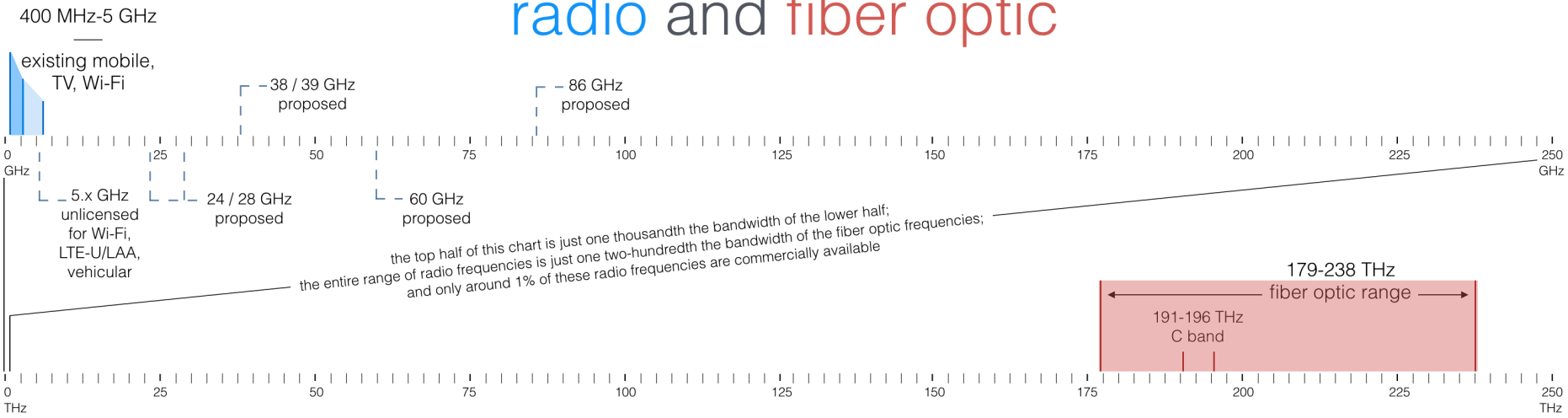

Band Gap: The lower half of this chart depicts the electromagnetic spectrum from 0 to 250 terahertz (THz), or trillions of cycles per second. The lasers of fiber optic communication operate in the upper portion of this range, the near-infrared spectrum, seen in red. The chart's upper half shows the radio spectrum between 0 and 250 gigahertz (GHz), which is just a tiny sliver — one one-thousandth — of the lower half. The blue slices of spectrum at top left contain nearly all existing broadcast TV, satellite TV, mobile, and unlicensed wireless (e.g. bluetooth, Wi-Fi) and are just a tiny sliver of all radio spectrum. A carrier of 4G mobile signals, which is typically 5 MHz wide, has just one millionth the bandwidth of the optical C band, which is 5 THz wide and is the most commonly used fiber optic range.

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Bandwidth:
mobile, unlicensed, fixed wireless

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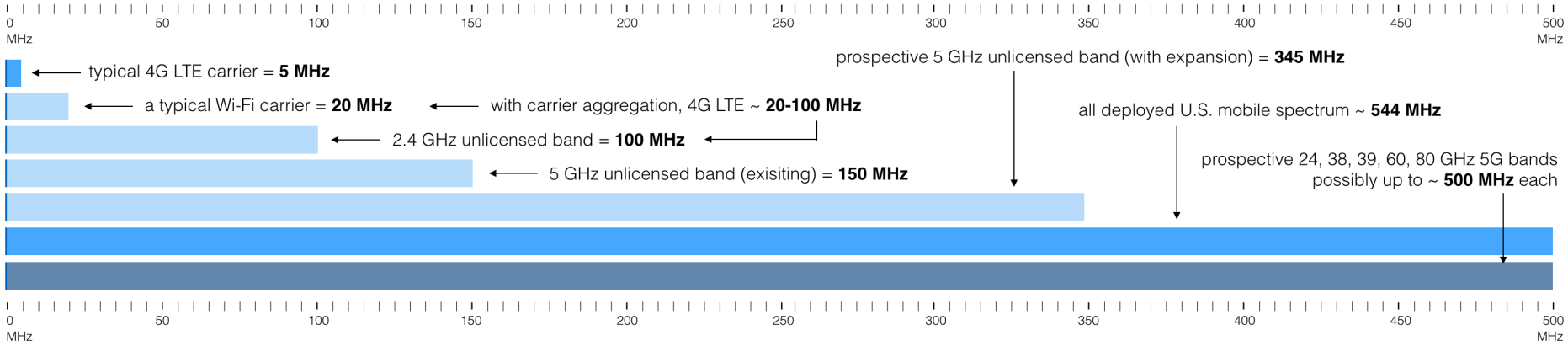

A 10,000% Boost: Bandwidth is the defining constraint on information transmission. The wider the band, the more information can be transmitted. Unlike the previous figure, which shows both the bandwidth and the "location" on the electromagnetic spectrum of the various bands, the blue bars here represent not the frequency locations but the size of the bands — the bandwidth. All deployed licensed mobile spctrum in the U.S. today totals 544 MHz. A typical carrier of a particular 4G mobile signal is 5 MHz wide (and potentially as large as 20 MHz). Combining these 5-20 MHz carriers using a technique called carrier aggregation can yield wider carriers of between 20 and 100 MHz. Some of the prospective up-spectrum 5G bands could each be 500 MHz, or a hundred times wider than the typical 4G carrier.

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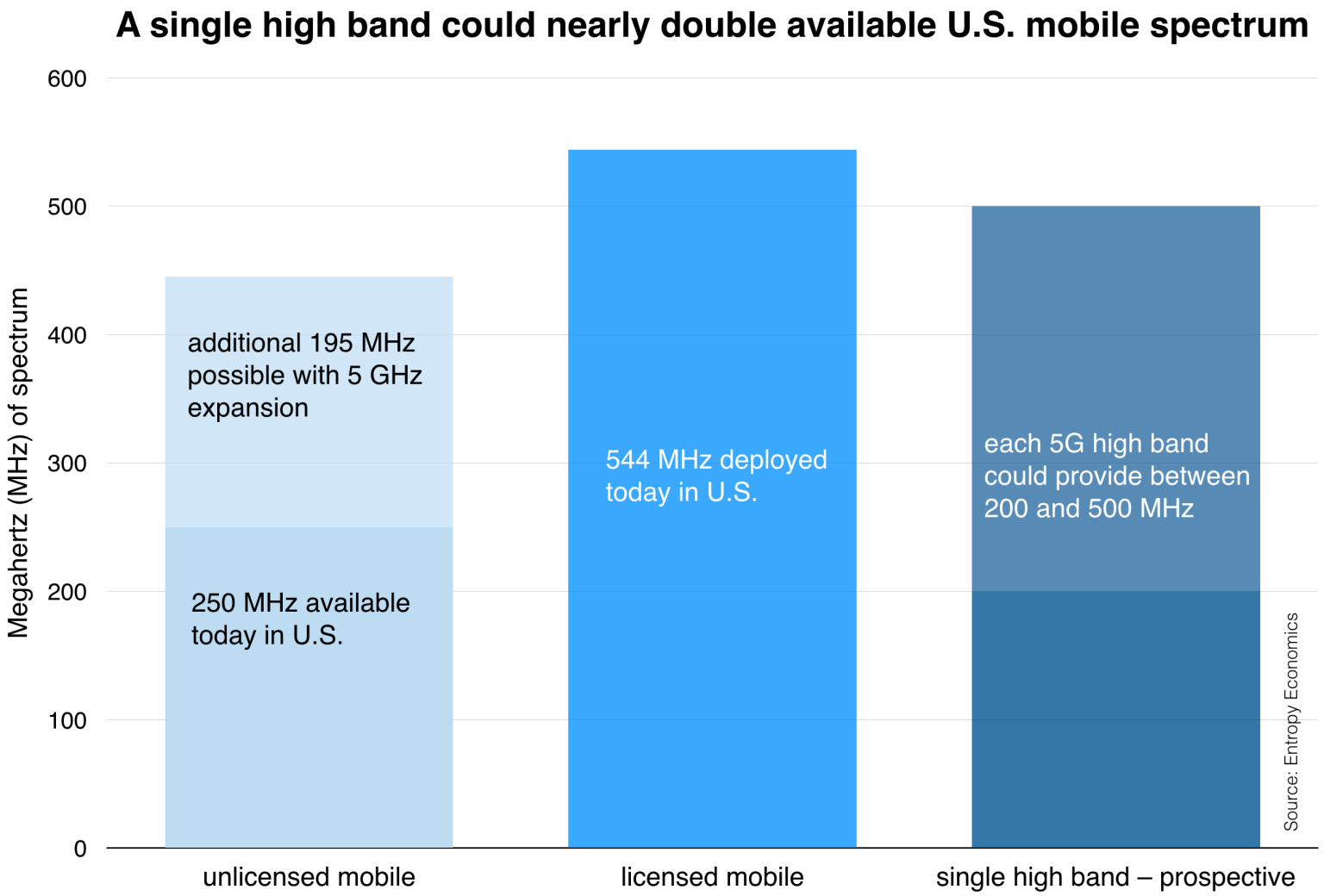
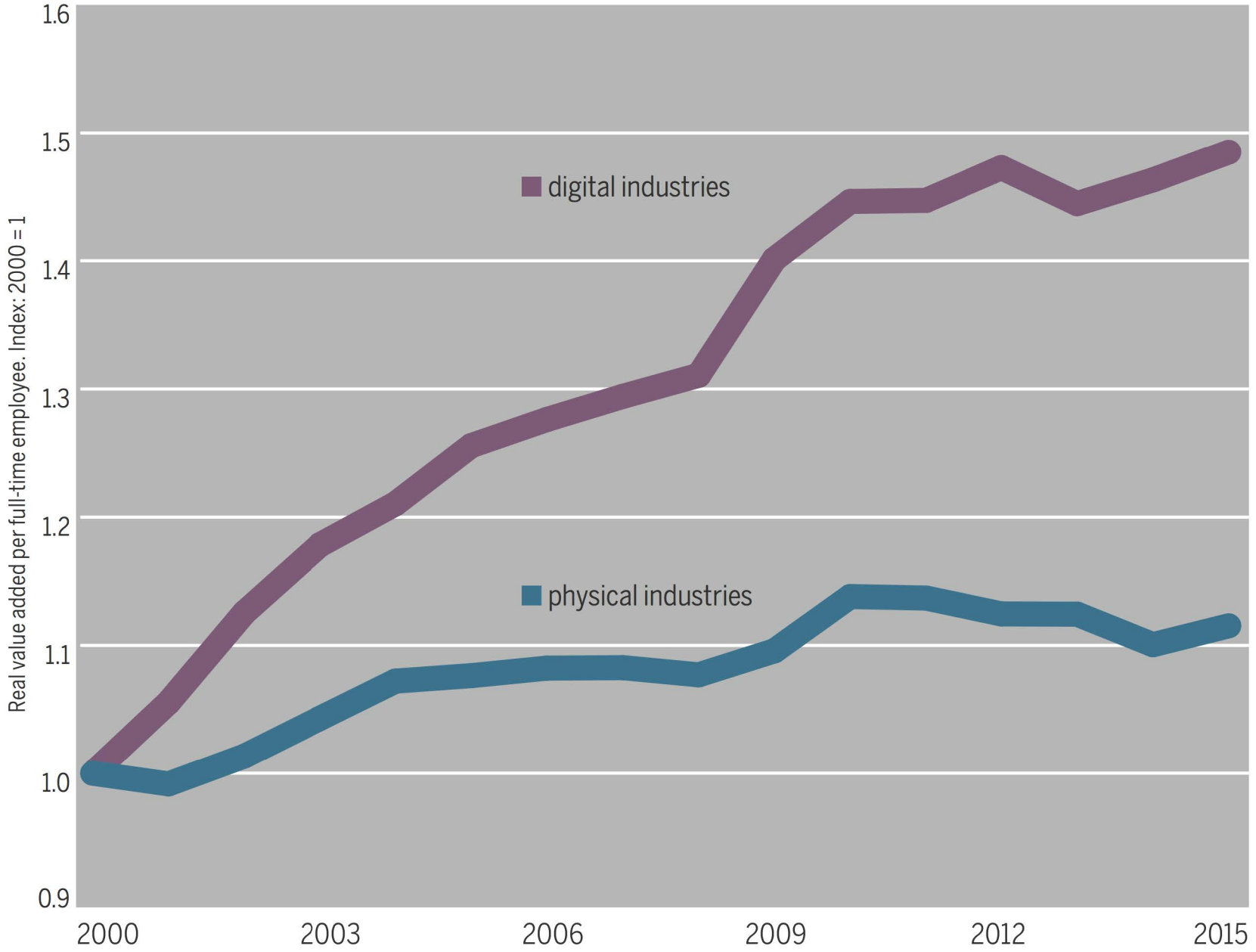


The Economic Impact

- Slow growth over last decade means today's U.S. economy is nearly $3 trillion smaller than we might have expected in 2007.
- We estimate faster productivity growth in the physical economy could boost annual output growth from the predicted 2.0% to 2.7% – yielding many trillions in more income and government revenue.
- 5G will be important platform for giving our lagging industries this productivity boost

figure 3. **PRODUCTIVITY GROWTH: DIGITAL VS. PHYSICAL**



Sources: Bureau of Economic Analysis, author calculations

figure 2. **INVESTMENT IN INFORMATION TECHNOLOGY AND SOFTWARE**

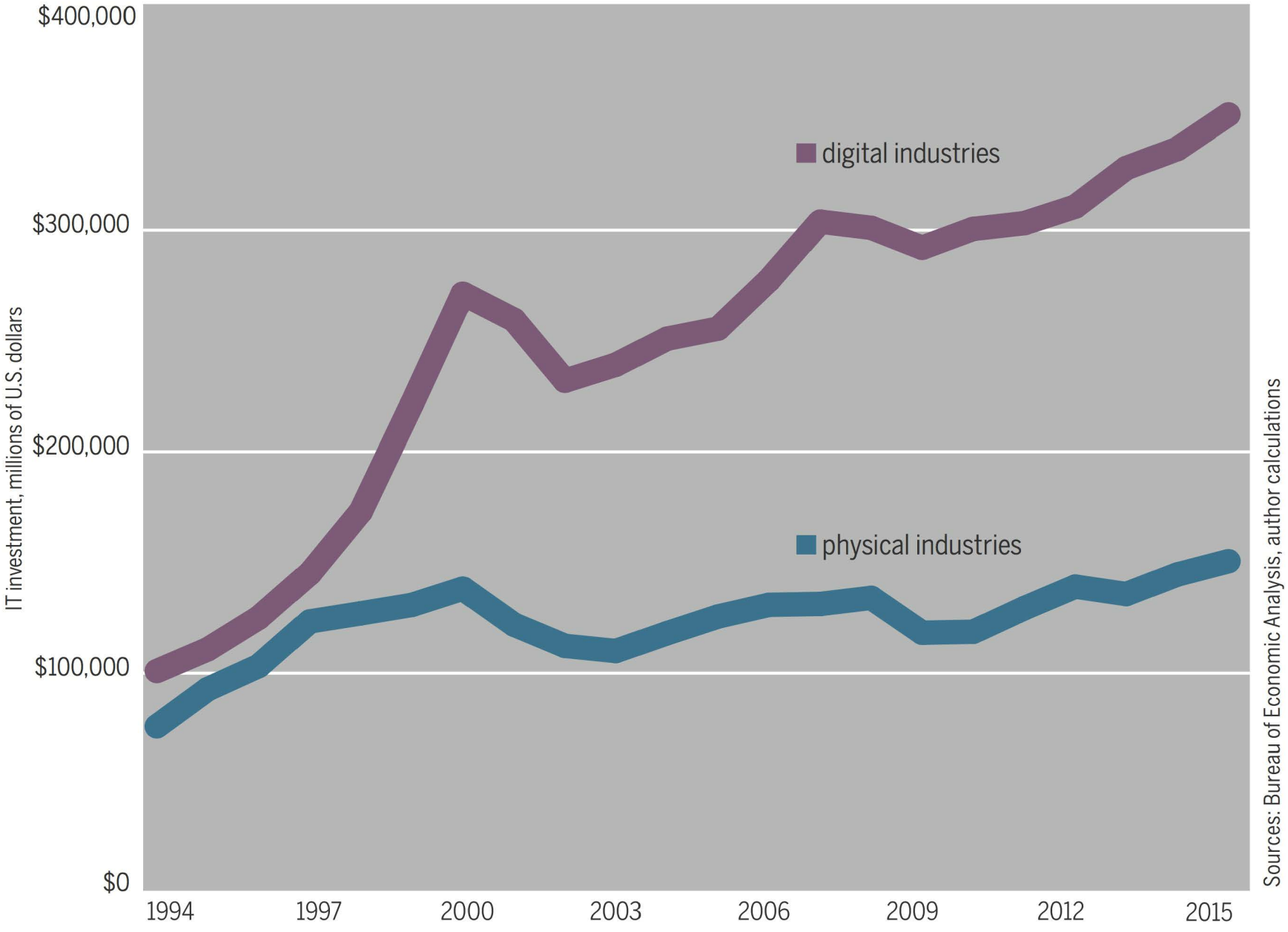
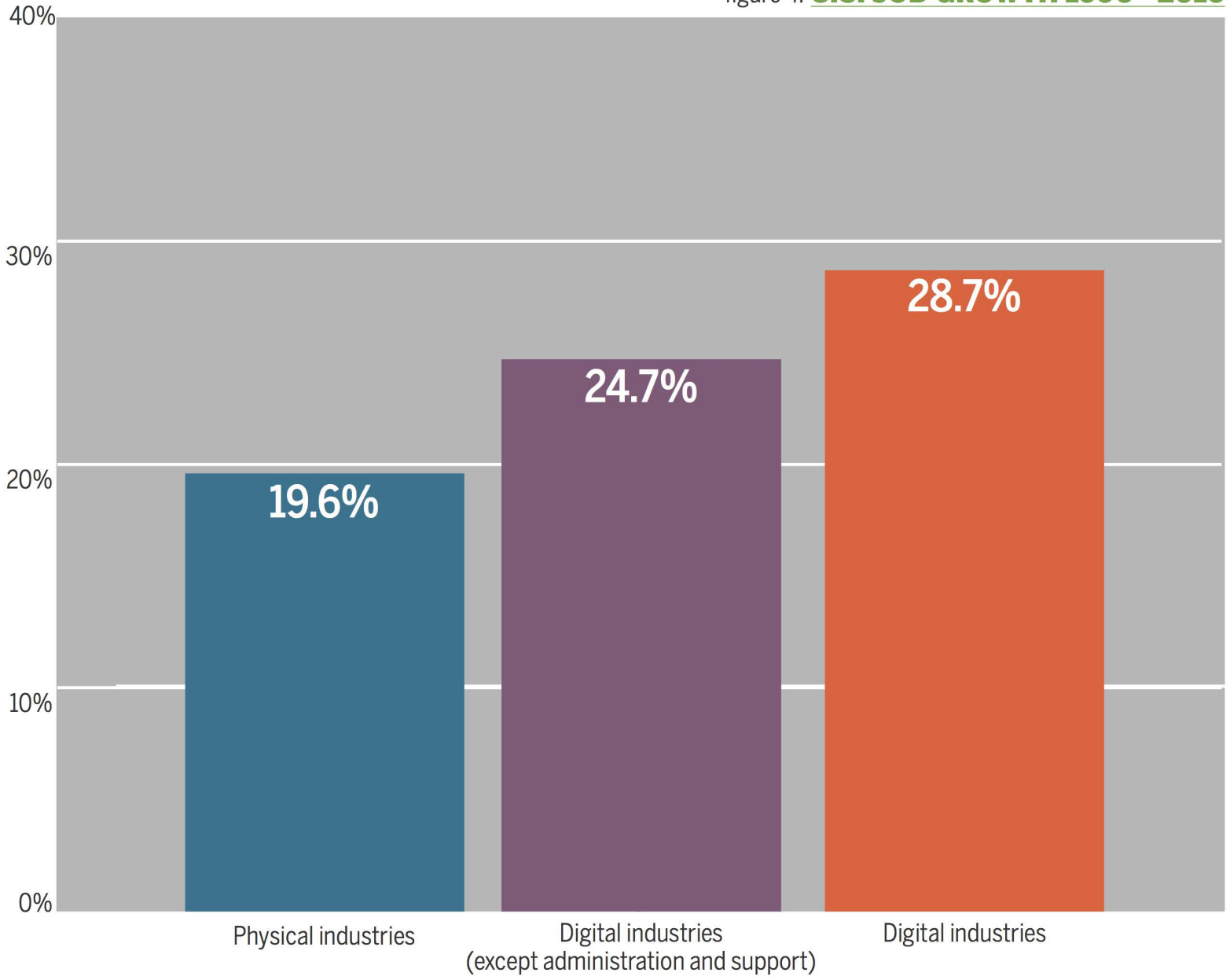


figure 4. **U.S. JOB GROWTH 1996—2016**



Sources: Bureau of Labor Statistics, author calculations

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- Straight Path Communications (STRP) is example of move “up spectrum”
- 39 GHz licenses, mostly nationwide
    - very wide bands = 200-600+ MHz
- also 28 GHz in parts of U.S., previously known as LMDS in 1990s
- bidding war between AT&T (T) and an “international telecom firm”

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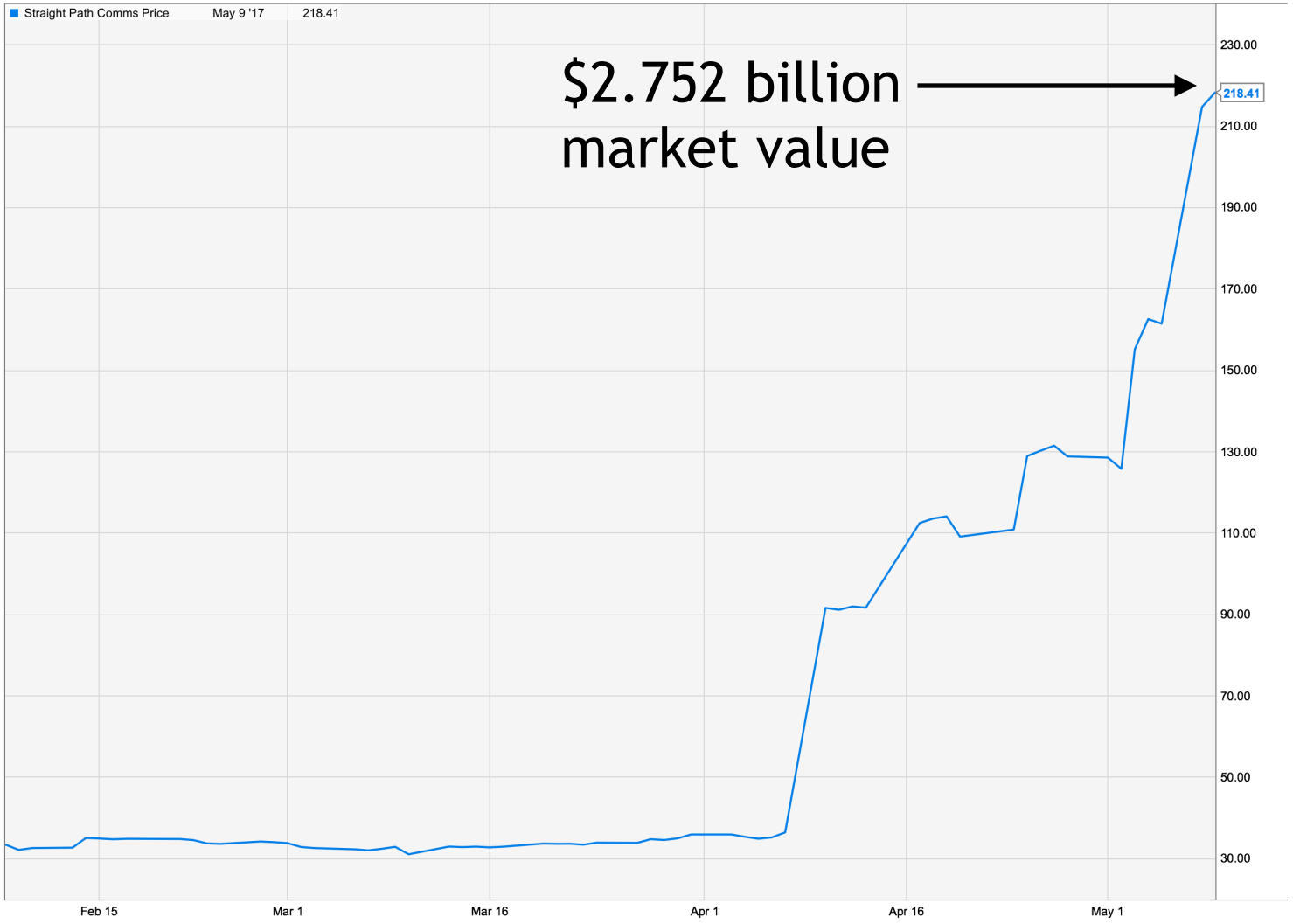

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How the Internet will become the 'Exanet'

"If the first several decades of Internet were based on interoperability through digital packet switching and expanded capacity via fiber optics and broadband, the next phase will (in addition to continual capacity additions) focus on ubiquity, latency, reliability, application diversity, and security."

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Recent reports, articles, podcasts…

- Imagining the 5G Wireless Future: Apps, Devices, Networks, Spectrum – Entropy Economics – November 2016
- 5G Wireless Is A Platform For Economic Revival – The Hill – December 2016
- 5G and the Internet of Everything – TechFreedom Podcast – December 2016
- How the Internet Will Become the 'Exanet' – Forbes – February 2017
- The Coming Productivity Boom: Transforming the Physical Economy with Information – Technology CEO Council – March 2017
- The $12-million iPhone – AEI – August 4, 2017

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Global Innovation + Technology Research

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