



Wireless Communications and the Internet of Things (IoT)

19 June 2017

Dr. Keith Gremban, Director

Institute for Telecommunication Sciences (ITS)

National Telecommunications and Information Administration (NTIA)

The Internet of Things (IoT)

“Things” connected to each other and the Internet

- Sensing
- Computing
- Communications
- Actuation



Health & Fitness



Smart Grid



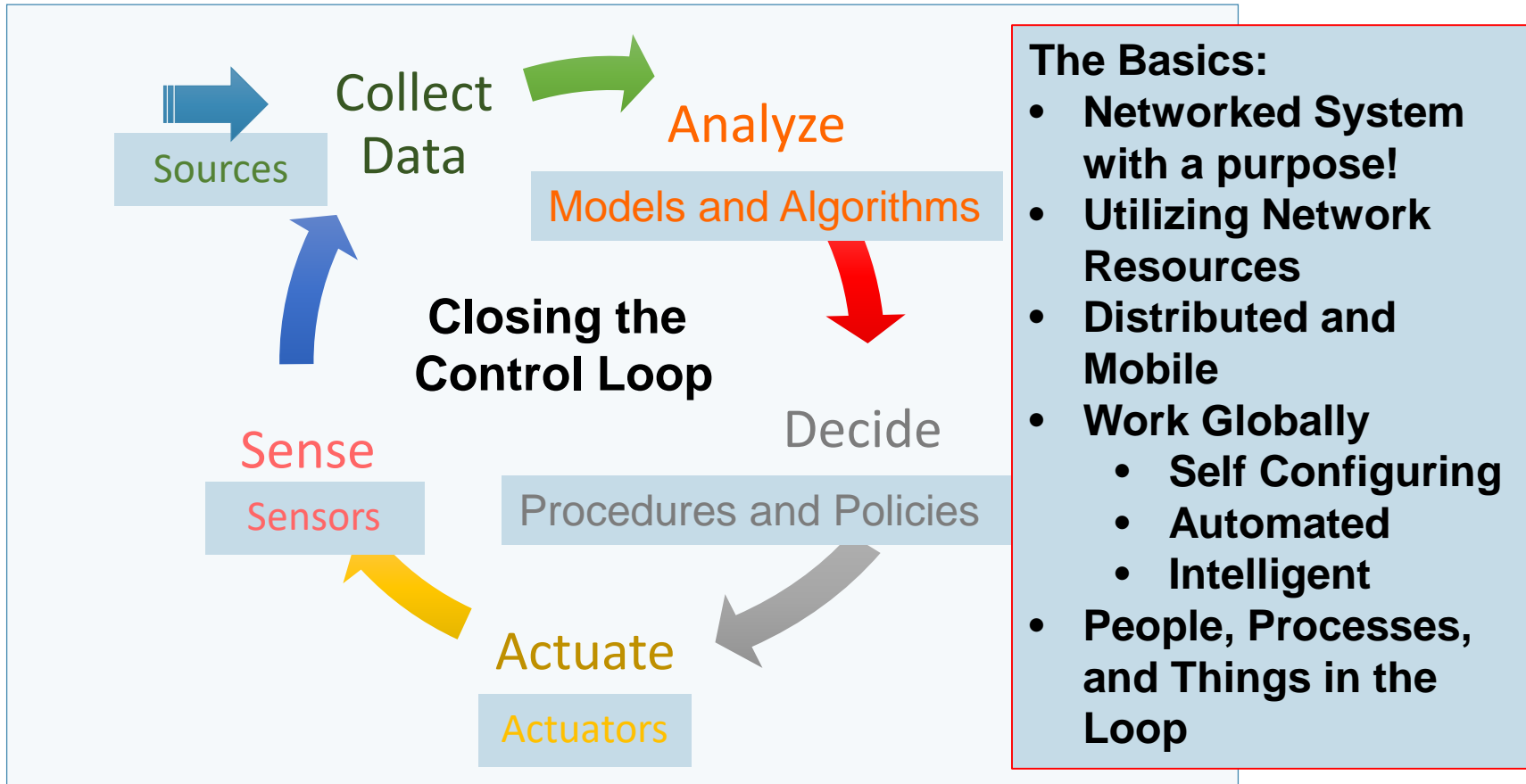
Agriculture



Transportation



What is IoT?



The Basics:

- **Networked System with a purpose!**
- **Utilizing Network Resources**
- **Distributed and Mobile**
- **Work Globally**
 - **Self Configuring**
 - **Automated**
 - **Intelligent**
- **People, Processes, and Things in the Loop**



We'll be Data Rich!

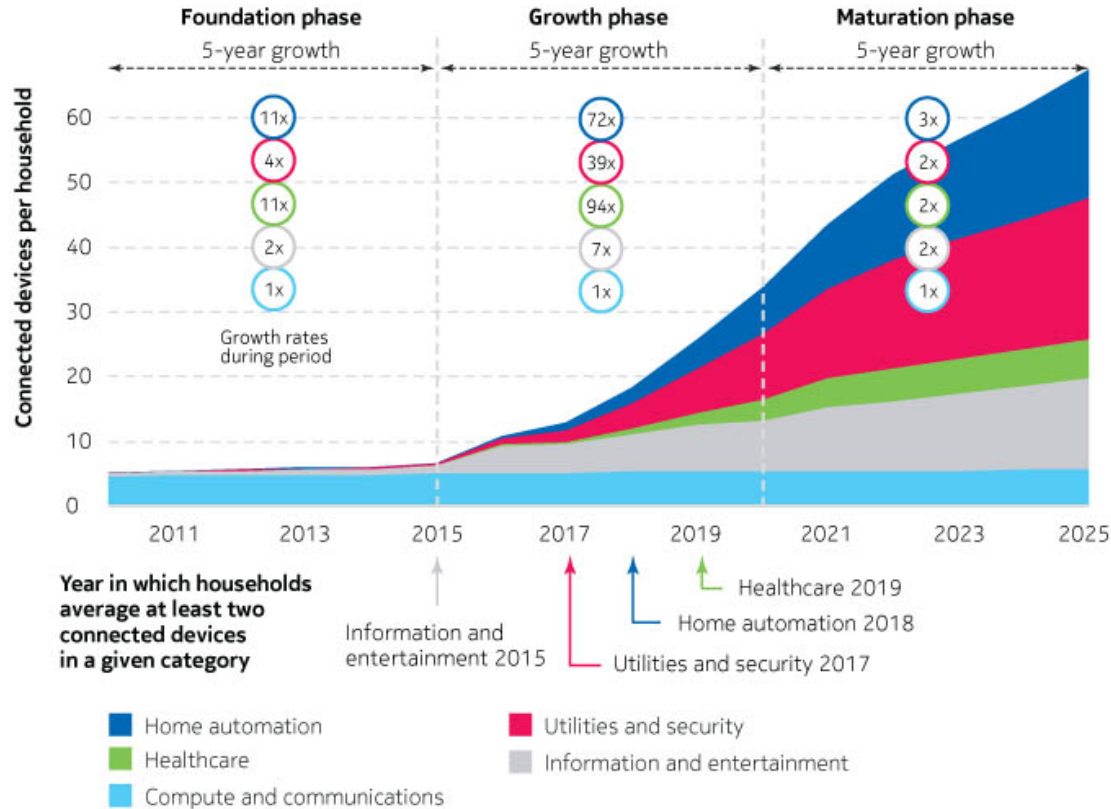
- IoT sensors will collect enormous amounts of data
 - Some sources estimate 200 billion connected devices in 2020¹
 - Some sources estimate 25 billion connected devices in 2019²
 - With 10 billion M2M (or IoT) devices
 - Simple sensors transmit between 1 MB/month and 1 MB/day
 - 1 MB/day is like checking a news website once a day
 - Video sensors could transmit much more
 - Excellent quality SD video is 13.85 GB/day³—7 months of a 2 GB/month wireless data plan or 166% of a 250 GB/month data cap

1. <http://www.intel.com/content/www/us/en/internet-of-things/infographics/guide-to-iot.html>

2. http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/VNI_Hyperconnectivity_WP.html

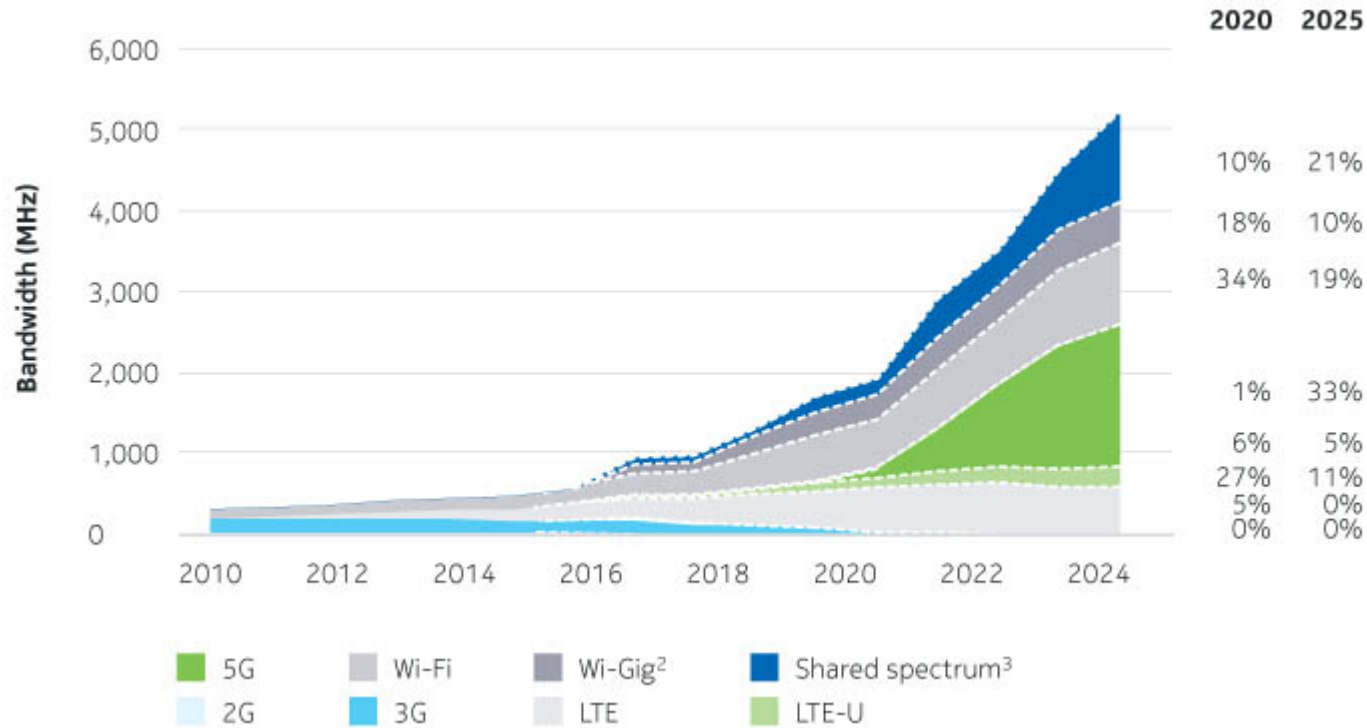
3. 1282 Kb/second for 86,400 seconds, H.264 high profile, CBR

7 Connected Devices → 70



The Future X Network: A Bells Labs Perspective (2016): connected devices per home will increase from 7 in 2015 to 70 by 2025.

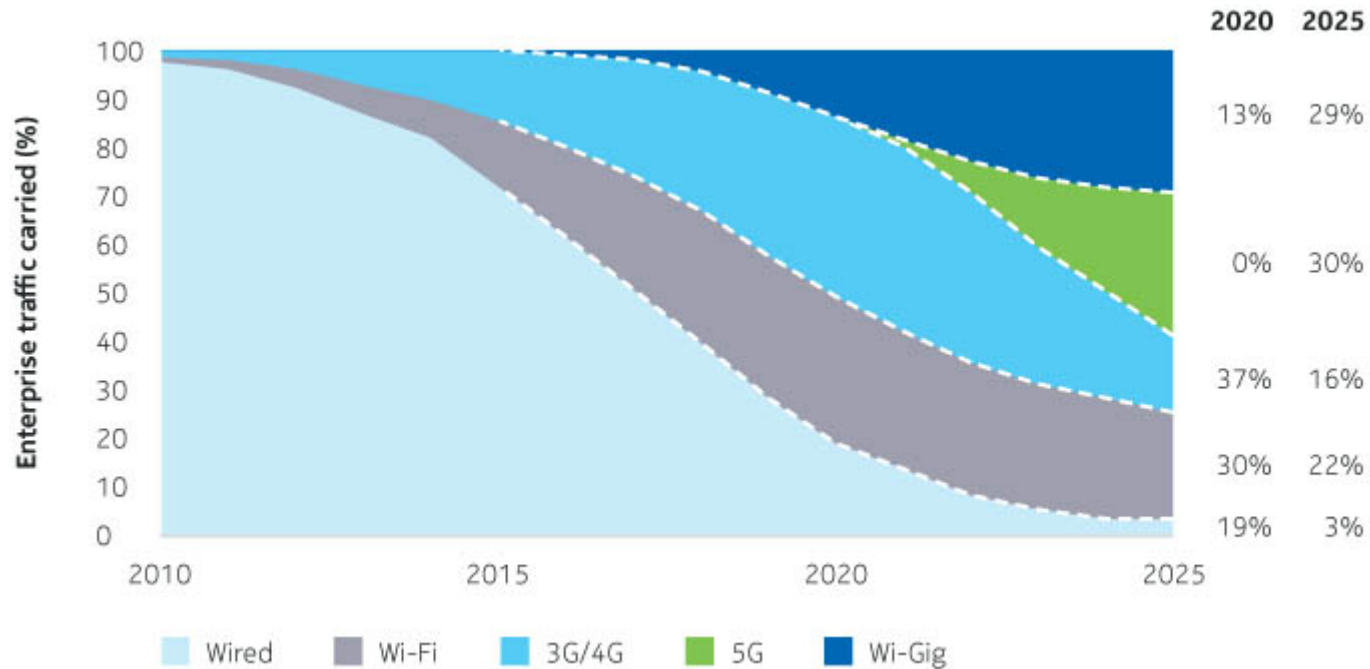
6 × Increase in Bandwidth Requirements



The Future X Network: A Bells Labs Perspective (2016): amount of spectrum bandwidth needed by 2025 for wireless enterprise traffic is expected to increase 6 fold.



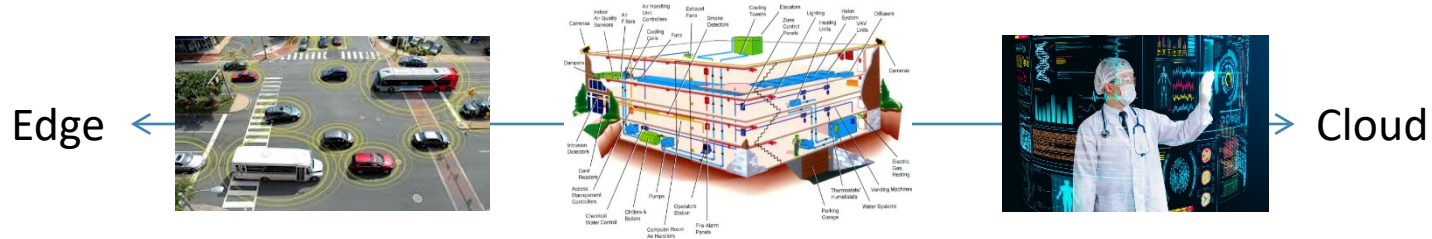
97% Wired → 97% Wireless



The Future X Network: A Bells Labs Perspective (2016): enterprise systems will go from >97% all-wired in 2010 to >97% all-wireless by 2025.

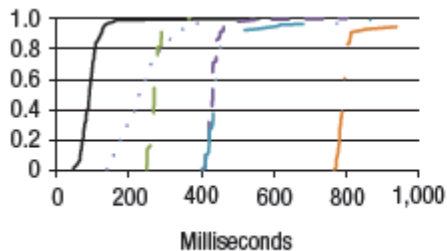
At the Edge? ... or ... To the Cloud?

- Trade resources: communication vs. computation
 - The edge minimizes communications, but computing may be limited
 - Powerful computing resources in the cloud, but burdens communications



- The time constant of the control loop is often the deciding factor

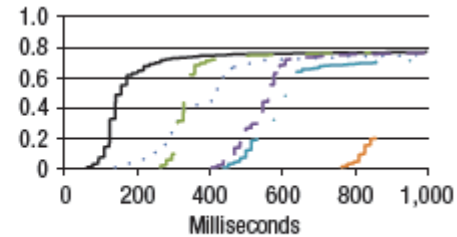
Augmented reality application



(a)

3.3 J	Mobile only	16.4 J
1.1 J	Cloudlet	5.4 J
3.1 J	AWS-East	6.6 J
5.1 J	AWS-West	8.5 J
5.2 J	AWS-EU	9.5 J
9.4 J	AWS-Asia	14.3 J

Face recognition application



(b)

From M. Satyanarayanan, "The emergence of edge computing," Computer, January 2017

Figure adapted from K. Ha et al., "The Impact of Mobile Multimedia Applications on Data Center Consolidation," Proc. 2013 IEEE Int'l Conf. Cloud Eng.



The First Hop is Wireless

- Billions of wireless devices have impact on the wireless spectrum
 - Contention
 - Multiple devices competing for the same resource
 - Interference
 - Multiple simultaneous transmissions
 - Increased noise floor
 - Out-of-band-emissions from many device
- Wireless spectrum is a new attack vector
 - Spoofing
 - Jamming
 - Distributed Denial of Spectrum (e.g., wide area, wideband jamming)

Need to consider these issues before they become a problem!

Summary

- IoT deployments are not cookie-cutter
 - Variations in architecture, applications, and operations
- Communications is a key enabler of IoT
 - Need to identify/prioritize IoT support
- IoT is dependent on access to wireless spectrum
 - Secure the wireless connection

