Where is the Internet of Things going?

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Outline

- Where is the *Internet* going?
- What makes the IoT different?
- Applications of the IoT
- Enablers of the IoT

Where is the Internet going?

- All-optical backbone (transmission *and* switching)
- Open flow switches? QoS?
- Software defined networks? SDN/SDI?
- Wireless + Optical

What makes the IoT different?

- *Smart* Sensors and Actuators
  (i.e., computers with strange I/O devices)
- Trillions of endpoints
- Real-time requirements
- Mobile/remote, low/no power
- An even bigger tsunami of data
- Even bigger cybersecurity risks

IoT in the terminology stack

- Lowest layer: Internet
- Lower layer: IoT--connecting the physical world (things) to the Internet
- Middle layer: Robotics (in the small) and Cyberphysical Systems (in the large)
- Upper layer: Applications

Applications of the IoT

- Smart cities, homes, cars, ...
- Smart grid, atc, voting, ...
- Smart scientific instruments (e.g., LHC)
- What's next? (If I knew, I wouldn't tell you.)

IoT Enablers

- The Cloud: virtual infrastructure for the IoT
- 5g: networking for the IoT
- Blockchain: cybersecurity for the IoT
- Digital objects: data architecture for the IoT
- Moore's Laws

The Cloud

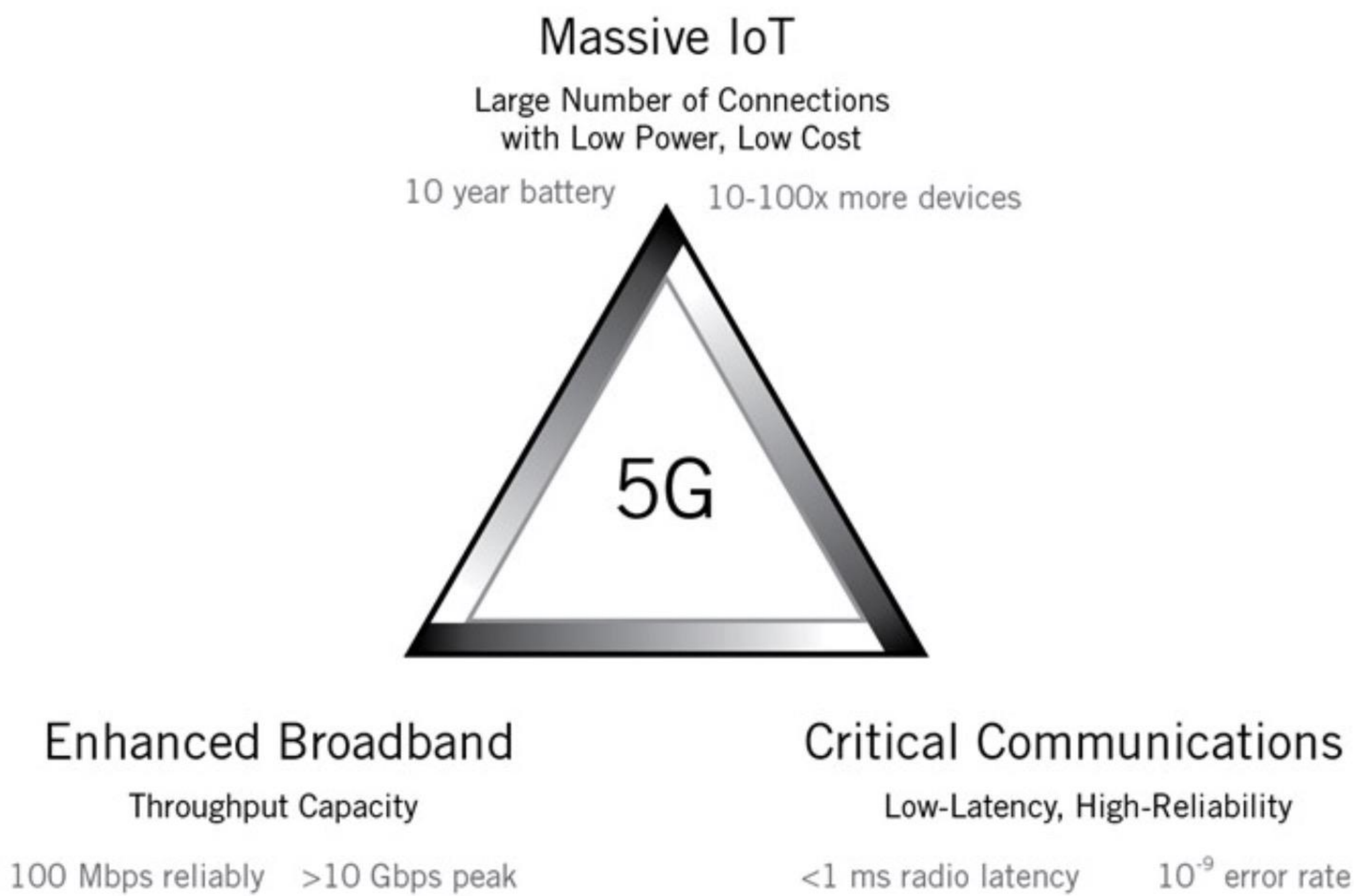
- Internet of Things aka the Industrial Internet
- Cloud Computing aka the Industrialization of Computing
- Exchange capital costs for operating costs
- SaaS, PaaS, IaaS
- Clouds of clouds

5g Mobile

5g: Networking for the IoT

- 1g: 1980s. Analog
- 2g: 1990s. GSM/TDMA (telephone tech)
- 3g: 2000s. CDMA (Internet tech)
- 4g: 2010s. LTE
- 5g: 2020s?

5G Triangle


Massive IoT
Large Number of Connections
with Low Power, Low Cost
10 year battery
10-100x more devices
5G
Enhanced Broadband
Throughput Capacity
100 Mbps reliably
>10 Gbps peak
Critical Communications
Low-Latency, High-Reliability
<1 ms radio latency
10^{-9} error rate

Massive Internet of Things

IoT at a much larger scale requires changes throughout the network.

- 5.5 million "things" connected every day of 2016; total of 20.8 billion IoT devices connected by 2020 (Gartner estimates).
- 3G and 4G not designed for IoT.
- Must support simplified signaling, cost-efficient devices, and long battery life (goal is 10 year battery life).
- But adaptability is key. Not all "IoT" devices are low-bandwidth; some mobile, some stationary.
- Competing with solutions based on unlicensed spectrum.

Technology behind 5G

5G not simply a new standard, but a collection of diverse technologies, many still under development.

Three key technologies:

- High-band or "mmWave" spectrum
- Advanced antenna technology
- Software-based networking

Blockchain

Blockchain: cybersecurity for the IoT

- A ledger of all legitimate transactions that have occurred on the network so far, which is maintained by the collaborative efforts of all the nodes in the network.

- A “trustless” system where nobody has to put their faith in anyone else, because the blockchain network itself is guaranteed to keep a fair and accurate record.

- Used to track and verify any kind of digital exchange.

Blockchain + IoT

- Track the unique history of individual devices, by recording a ledger of data exchanges between it and other devices, web services, and human users.
- Enable smart devices to become independent agents, autonomously conducting a variety of transactions.
- Blockchain networks themselves also have the potential to become independent agents, what some have referred to as “Distributed Autonomous Corporations."

IoT Transactions

- In the absence of a centralized server brokering messages, supporting file storage and transfers, and arbitrating roles and permissions, any decentralized IoT solution (e.g., blockchain) should support three foundational types of transactions:
- Trustless peer-to-peer messaging
- Secure distributed data sharing
- A robust and scalable form of device coordination

Digital Object Architecture (DOA)

DOA Origins

- The Internet was designed and implemented as a general purpose platform to provide global connectivity among computers, devices and networks of all kinds.
- In the mid 1980s, it became apparent that *information management* was a kind of specialized application that had the potential for being a platform that made use of the existing Internet infrastructure, but offered a new set of capabilities that were likely to be of widespread utility.

DOA and the Web

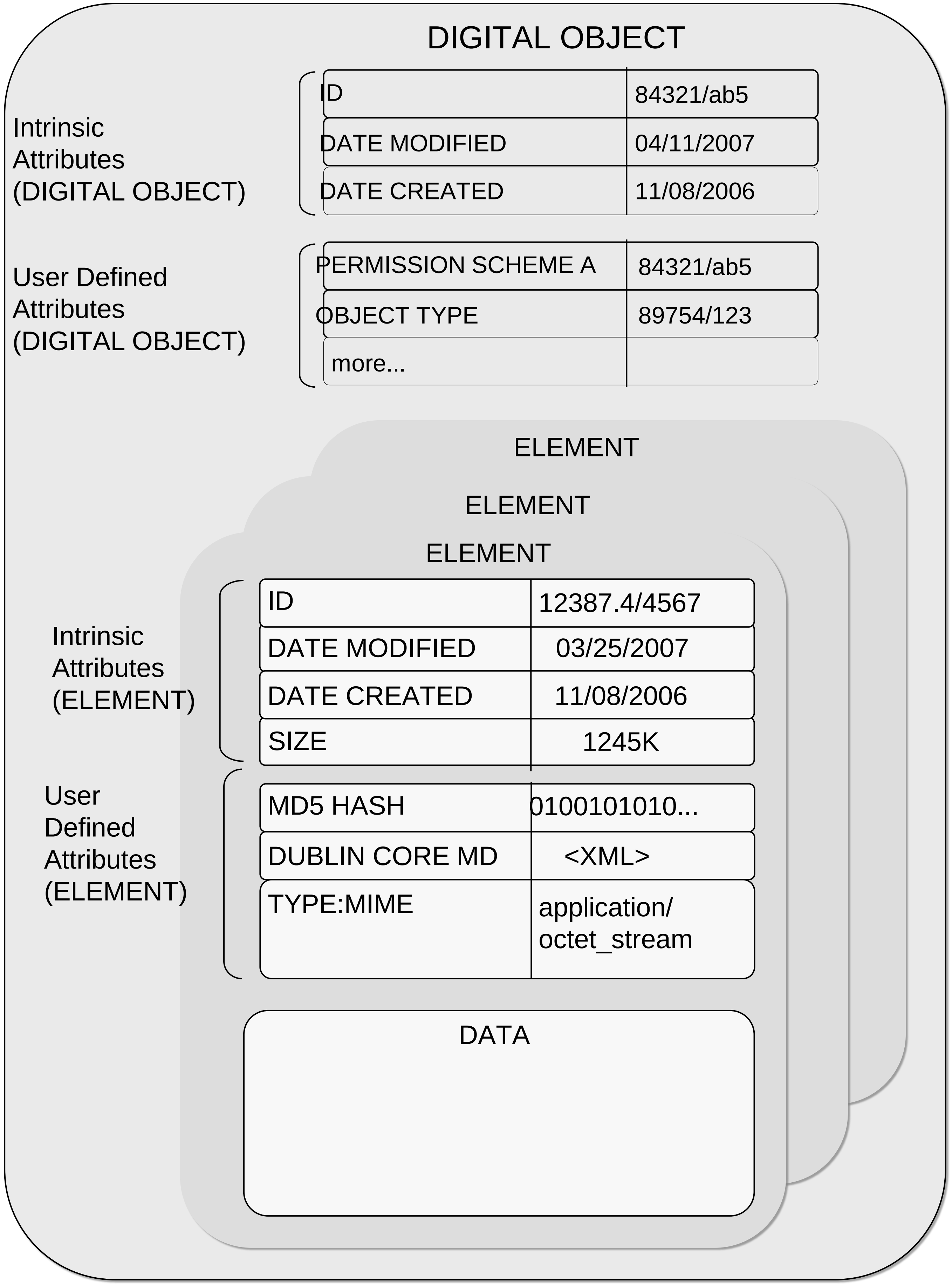
- The Digital Object Architecture and its development proceeded *in parallel* with that of the World Wide Web.
- The Web acquired more rapid acceptance since it focused primarily on one type of (public) information, limited security, and near-term access.
- The DOA was designed to enable *all* types of information, whether public, private, or some combination thereof, to be managed in a network environment over potentially very long time frames; and it includes the capability for integrated public key management within the same infrastructure used to manage other information.

Digital objects for the IoT

- The core components of the architecture have all been implemented and made available on the Internet by Corporation for National Research Initiatives (CNRI).
- The infrastructure aspects of the DOA allow interoperability to be easily achieved technically by parties that wish to enable it administratively.
- The technology for an *Internet of Things* is essentially about managing information about the things and could thus be managed using components of the architecture.

DO Architecture

- The basic architecture contains two distinct component types, *handles and digital objects*, of which an unlimited number of instances of each type is possible
- Two special kinds of digital objects are digital repositories and digital registries
- The architecture is independent of the underlying technology used to implement the components, just as the Internet architecture is independent of the choice of component networks that comprise it
- The implementation of the architecture is scalable along dimensions of size, and is evolvable with technology



- Each Object contains structured data and extensible metadata
- Metadata includes types, dates, permissions, and other relevant attributes

The Universal Enabler: "Moore's Laws"

- Transistors per chip: 1970--1K, 1990--1M, 2010--1G
- Bits per second: 1990--1M, 2000--1G, 2010--100G
- Bytes per $100: 1990--100M, 2000--10G, 2010--1T
- Sensors/actuators: discrete -> micro -> nano

In conclusion

Lives are changed when people connect. Life is changed when everything is connected.

Qualcomm motto

- http://sites.nationalacademies.org/cs/groups/pgasite/documents/webpage/pga_173948.pdf
- http://www.postscapes.com/blockchains-and-the-internet-of-things/#background
- https://en.m.wikipedia.org/wiki/Cloud_computing
- http://www.cnri.reston.va.us/papers/OverviewDigitalObjectArchitecture.pdf

Abstract

The Internet of Things (IoT) has been gradually emerging. It can be viewed as layer on top of the Internet of Computers (IoC). To speculate where the IoT is going, I begin by speculating where the IoC is going. Then I speculate about the developing characteristics of the IoT and those of the layer on top of it, that of cyberphysical systems. Finally, I discuss opportunities and challenges, such as the interoperability of heterogeneous data and cyberphysical security.