5G Journey: Path Forward

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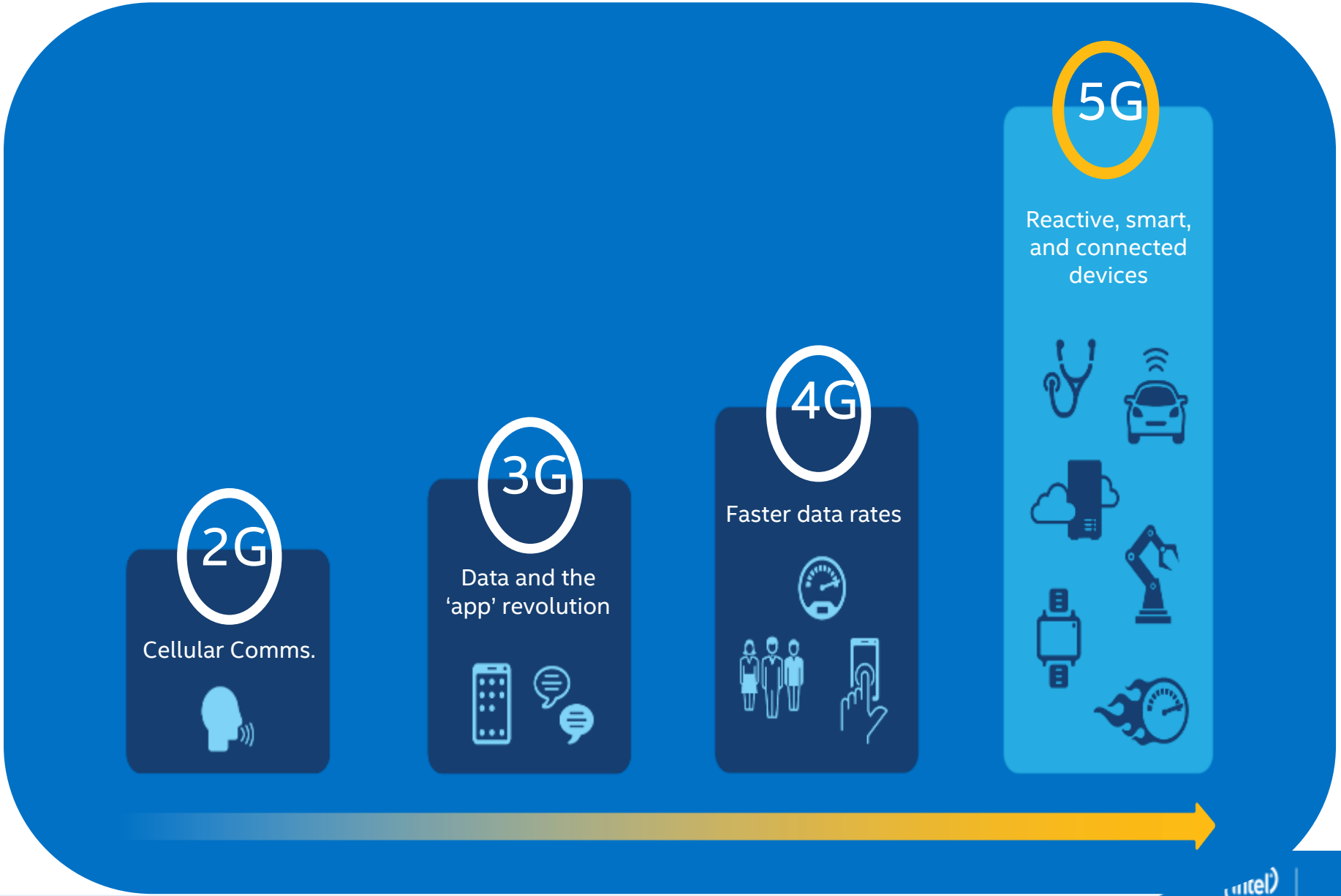
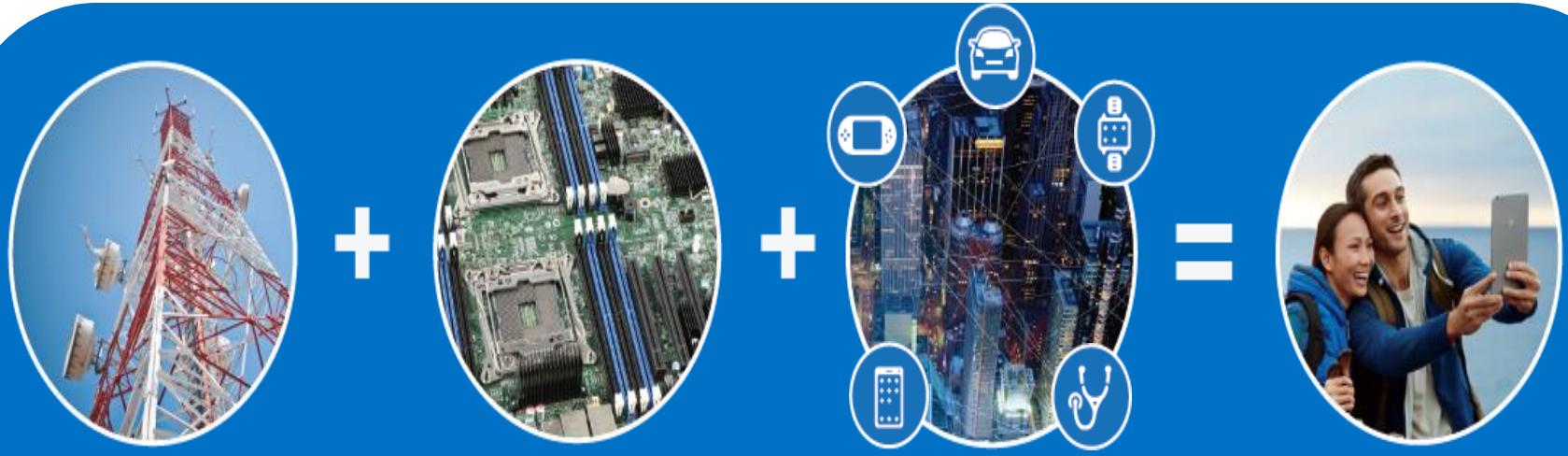
WE ARE HERE:


2G
Cellular Comms.
3G
Data and the 'app' revolution
4G
Faster data rates
5G
Reactive, smart, and connected devices

5G EXTENDS THE CLOUD TO THE MOBILE EDGE

High performance, Intel-powered analytics and services at the edge unlocks the network to new services



Radio

Compute
Storage

Healthcare
Connected Car
Positioning
Virtual Taps

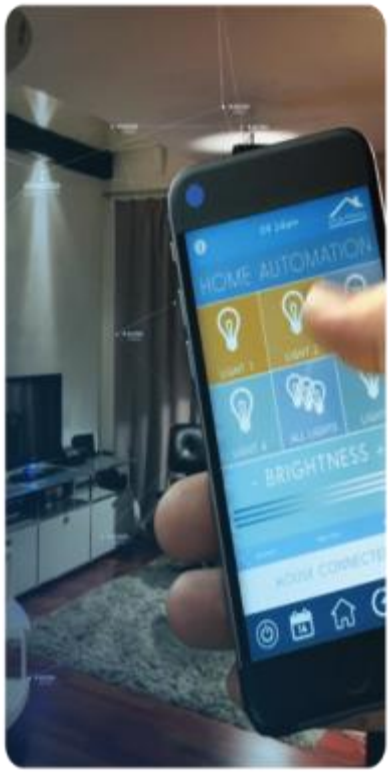
Gaming
Virtual Apps
Smart City
Caching

Better User Experience
Lower Latency
Streamlined Approach

IOT AND 5G WILL GENERATE A 5G DATA EXPLOSION

Industrial IoT

Intelligent Homes & Buildings



Smart Cities

Autonomous Vehicles

DIVERSE 5G TECHNOLOGIES WILL FUEL IOT SUCCESS

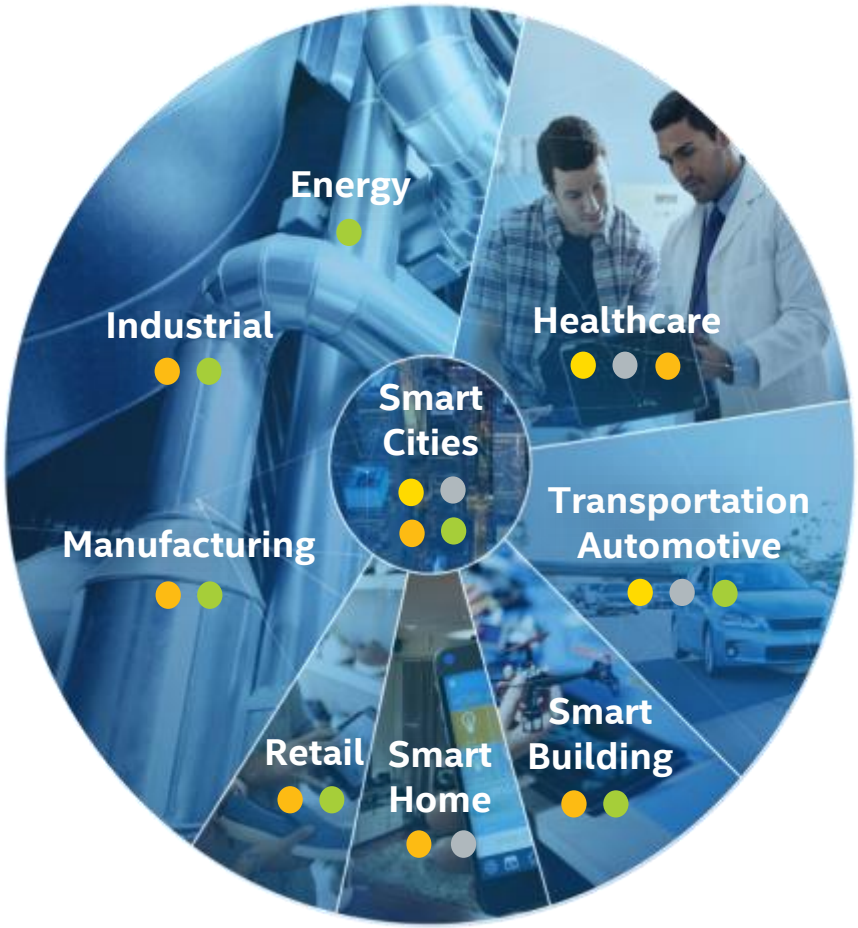
Intel 5G solutions will help grow IoT deployments by matching requirements to industry use cases

LTE ADVANCED PRO

NB-IOT

802.11AX

5G NEW RADIO

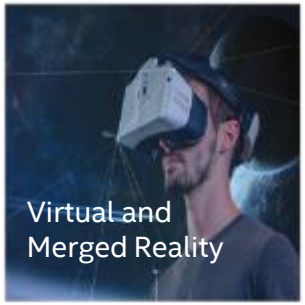


5G ENHANCEMENTS WILL TRANSFORM LIVES

Ultra Reliability and Low Latency

Massive M2M Connectivity

Enhanced Mobile Broadband



WHAT IS NEXT?

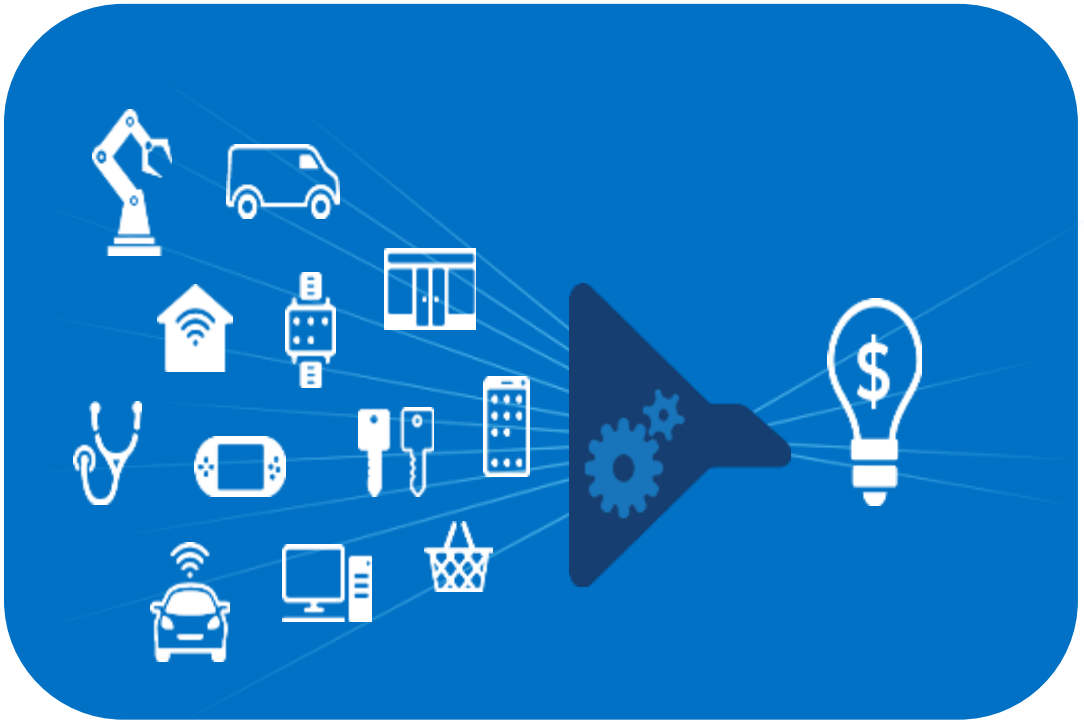
5G IS A CRITICAL ELEMENT OF THE NEW DATA ECONOMY

Connecting billions of devices will generate a massive wave of data. Only 5G has the scale and scope to enable new insights, drive business efficiencies, and create data monetization.

Autonomous Driving
1 GB/second

Smart Hospital
4000 GB/day

Connected Factory
1 million GB/day



Source: Amalgamation of analyst data and Intel analysis.
And VNI Global Traffic Forecast. VNI stands for Visual Networking Index.

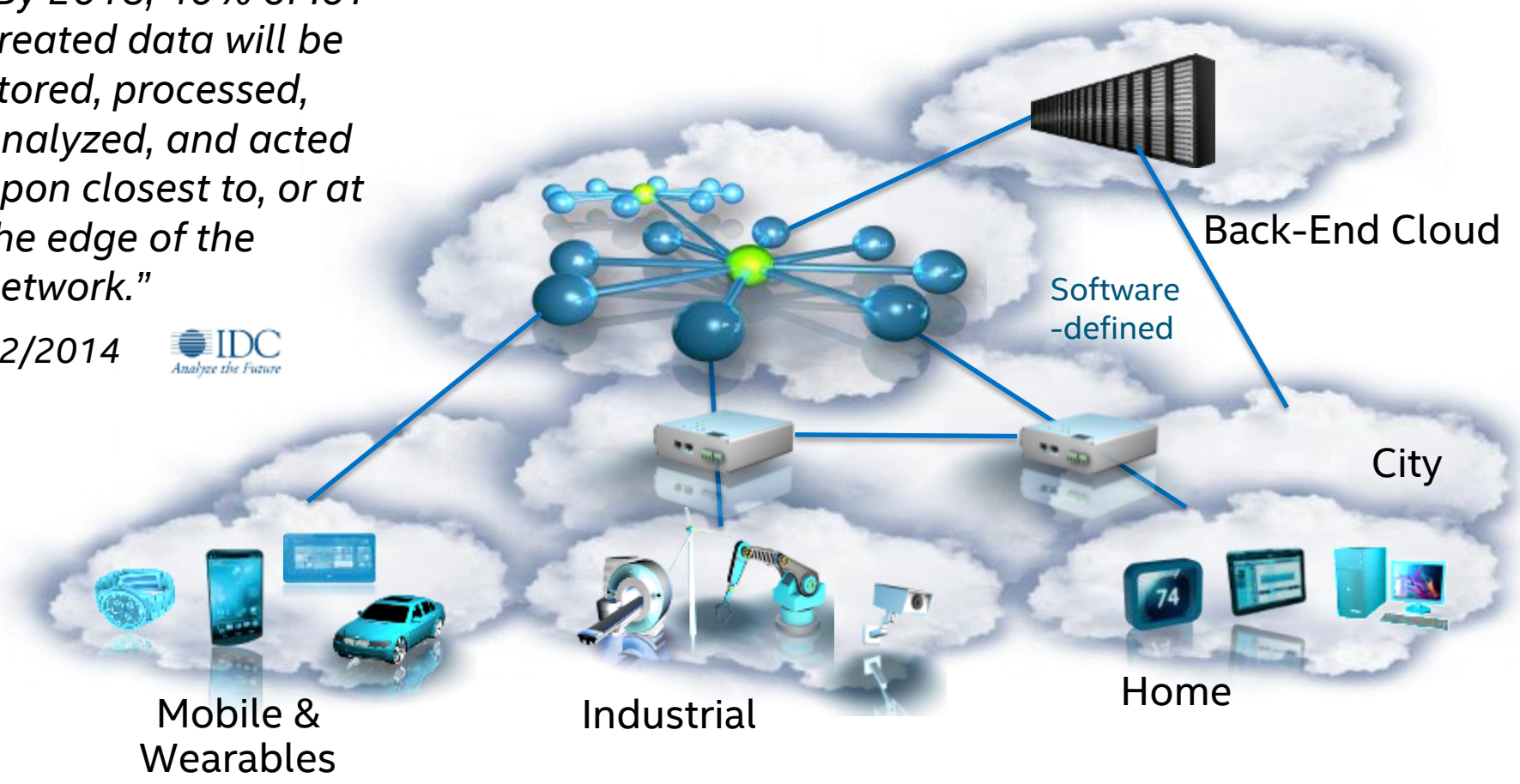

INFORMATION CENTRIC NETWORK
WIRELESS AUTONOMOUS SYSTEMS

Data Inversion Problem: IoT Edge data flows upstream

Cloud functionality migrating to be more proximate to the data

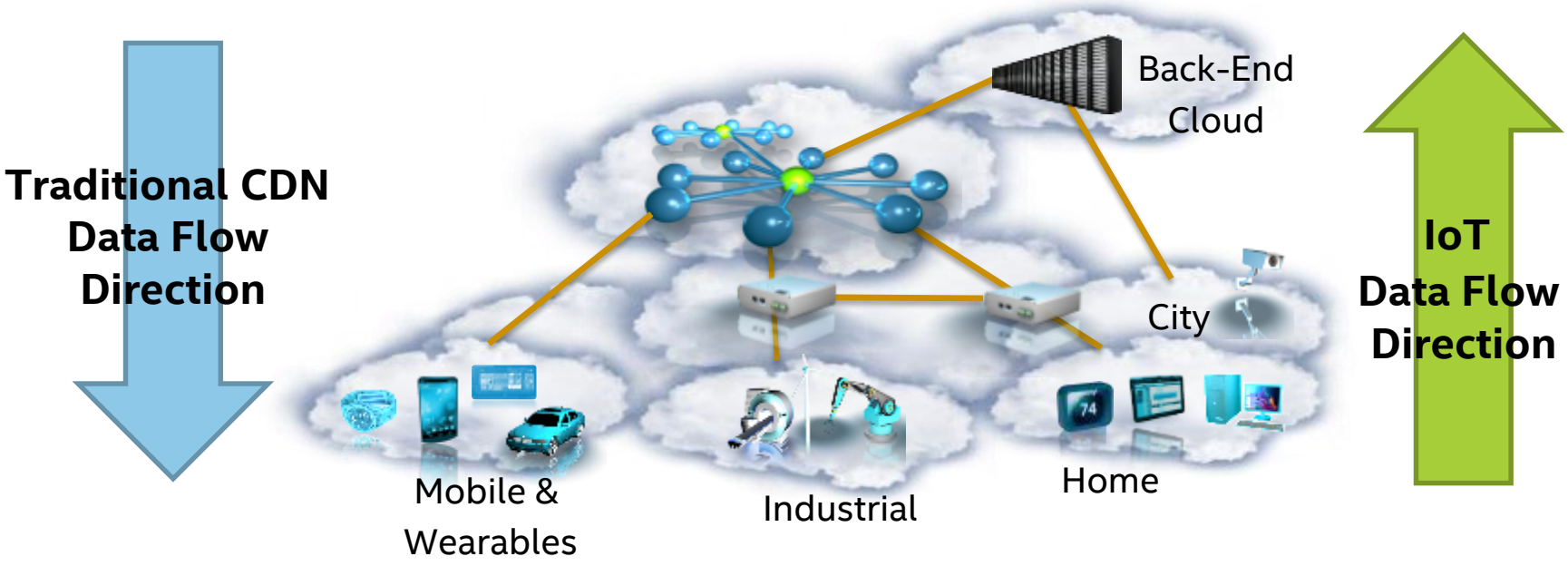
"By 2018, 40% of IoT-created data will be stored, processed, analyzed, and acted upon closest to, or at the edge of the network."

12/2014 IDC Analyze the Future



ICN: Need for Edge and Fog Computing

A Multi-tier Cloud of Clouds



Use ICN for rCDNs (reverse CDNs)?

Reverse data flows combining routing with storage and processing

ICN and 5G+ Networks

- ICN over wireless a natural next step
- 5G+ use cases very different from traditional ones
  - High BW and support for large #s of devices
  - AR/VR, autonomous vehicles, dense IoT, robotics, drones, etc.
- New usage models where source-dest model falls short
  - Source is inaccessible: *e.g., in sleep mode, offline, encounters congestion, mobility or interference*
- IoT Data
  - Data often originates and is processed at the Edge
    - May (not) flow back to the core
  - ICN enables access to data within the network
    - With less application dependence

NSF-Intel ICN-WEN Program:

$6.5M over 3 years, 2-3 projects to be awarded

- Focus on Wireless Edge Networks
  - Ultra low-latency and massive IoT applications
- ICN approach to 3 dimensions:
  - wireless device endpoints
  - wireless network infrastructure and architecture
  - wireless data security and privacy
- Clean-slate design
- Research goals: NSF 16-586
  - Create new integrated ICN approach for wireless nets
  - Address fundamental challenges of wireless ICN data delivery
  - Demonstrate & quantify benefits of a potential ICN-WEN
  - Evaluate realistic deployments & implementation complexities

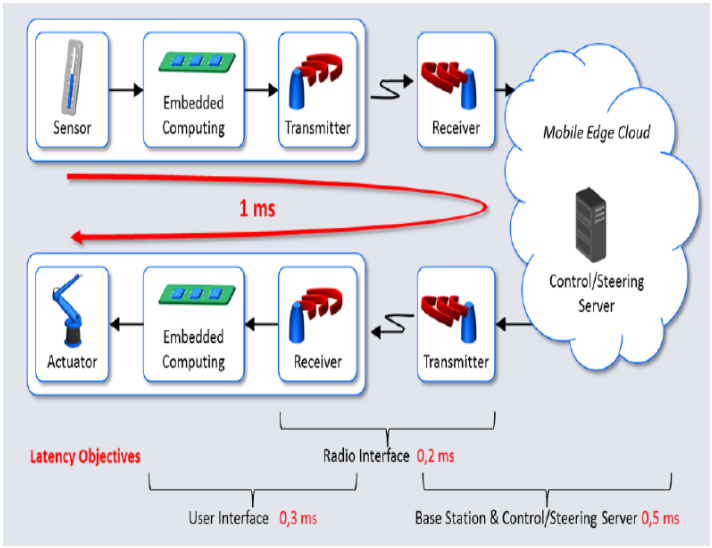

INFORMATION CENTRIC NETWORK
WIRELESS AUTONOMOUS SYSTEMS

5G+ networks to enable New Real-time Services

Autonomous Cars

Remote Controlled Drones

Robots



Sense, Compute and Communication Frameworks

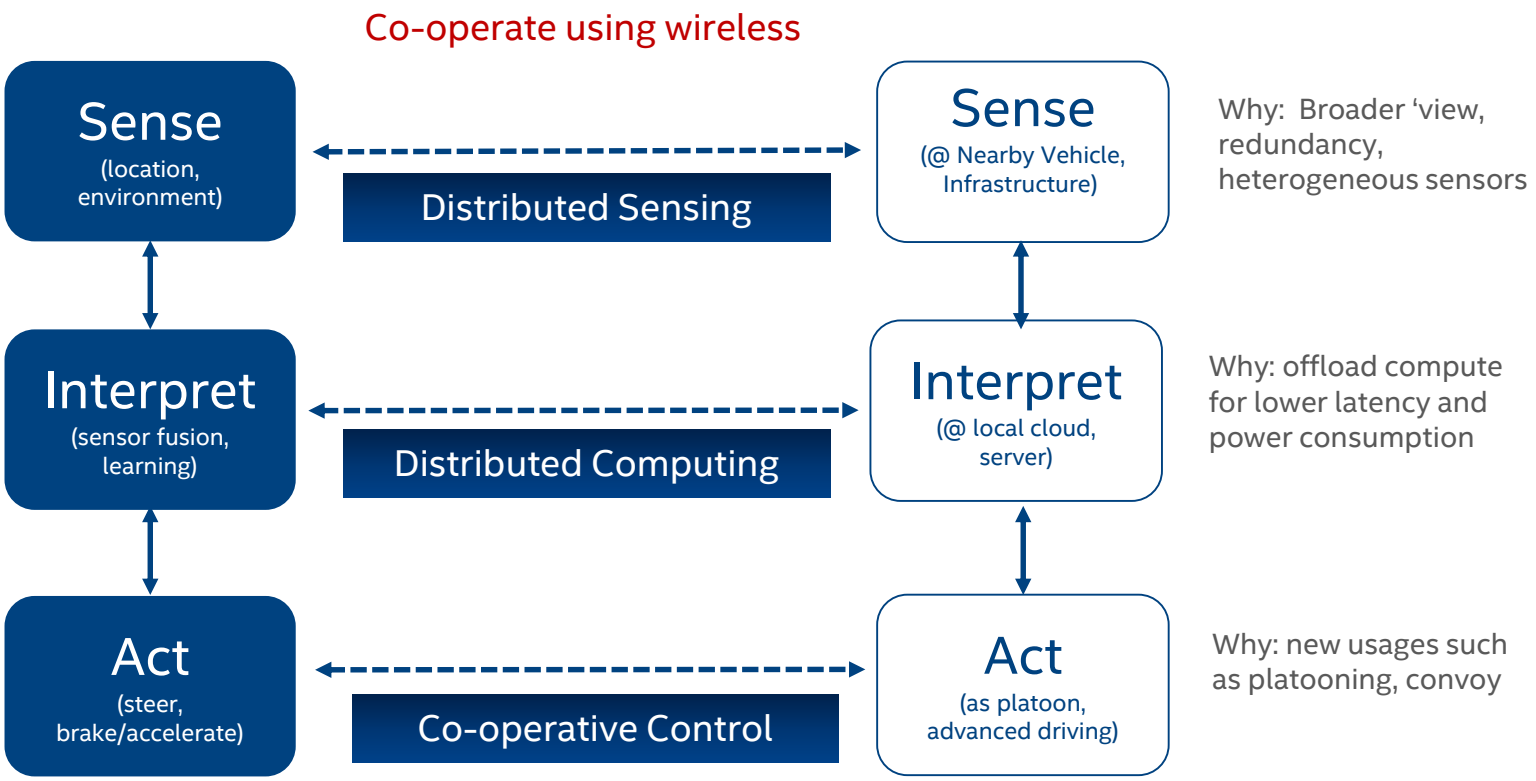
Intelligent, learning-enabled wireless platforms and networks that can reliably *sense, interpret and act* in real-time.

Source: ITU Watch Report on Tactile Internet

Integration of Sensing, Compute and Communication critical to achieve end-to-end QOS for control loop in autonomous services

Co-operative Cognitive Control: Autonomous Vehicles

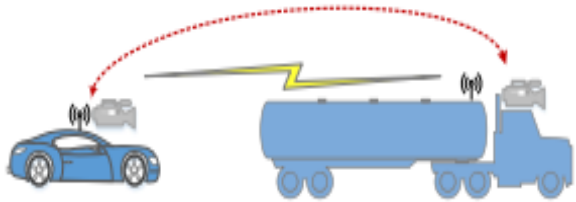
Extend cognitive control loop in autonomous vehicles to **distributed co-operation** using wireless networking (V2X) to **provably** improve decision making in the presence of wireless uncertainty



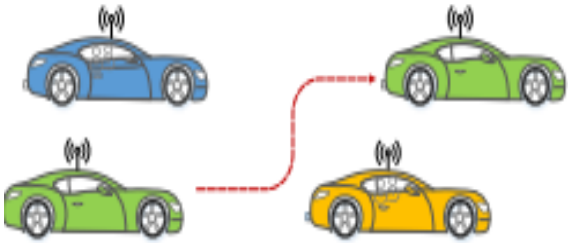
Some examples of Co-operative Cognitive Control

Platooning

Extended Sensor



Advanced Driving



Remote Driving

Wireless communication will expand the cognitive capabilities of autonomous vehicles

Summary of Existing Wireless Solutions

Extensive Industry & Research focus on Vehicular Networks

- Dedicated Short Range Communication –DSRC (IEEE 802.11p, WAVE)
- Rel. 14 LTE based V2X (similar performance, usage targets as DSRC)
- Rel. 15 LTE based V2X (phase 2) in progress
- Study for New Radio (NR) Based V2X in Rel. 15
  - eV2V evaluation methodology, evaluation scenarios, Side-Link channel model for above 6GHz

Intel Science & Technology Center on WAS

Context Aware Wireless Networking for Autonomous Systems

Research Goals:

- *Address challenges to enable safety critical AS over wireless networks.*
- *Emphasizes co-design of AS with wireless networking to ensure E2E QoS of Wireless Cognitive Control.*

A. Address Wireless Constraints in (Cooperative) WAS Cognitive Control Loop.

- Co-design critical autonomous system functions of sensing, computing/learning, and control, to comprehend and adapt to the unreliable and highly dynamic wireless radio environment.

B. Optimize Wireless Networking for WAS, using Context Aware, Learning Based Approaches.

- Address WAS with context aware, and learning-enabled wireless platforms and networks.
- Examples: learning approaches to learn radio environment towards improving localization, radio resource management, interference control.

Summary

- IoT Data causing disruption …
  - What's the network+compute+storage architecture needed?
  - What's the impact on privacy, security, trust models?
  - How/where to put the control?
  - Accessible anywhere? Safeguarded everywhere?
- Exciting and relevant areas of research for 5G+
  - Information Centric Network
  - Wireless Autonomous Systems

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