Fog Computing, its Applications in Industrial IoT, and its Implications for the Future of 5G

Flavio Bonomi, CEO and Co-Founder, Nebbiolo Technologies
IEEE 5G Summit, Honolulu, May 5th, 2017
Agenda

- Fog Computing and 5G: High Level Introduction
- Architectural Angles in “Fog” with Relevance to 5G
- Fog Computing and 5G: Natural Partners for the Future of Industrial IoT, with Applications
- Nebbiolo Technologies: Brief Introduction
- Conclusions
The Pendulum Swinging Back: A Renewed Focus on the Edge of the Network, Motivated by the Network Evolution, 5G and IoT

Fog Computing
Mobile Edge Computing
(Modern, Real-Time Capable) Edge Computing
Real-Time Edge Cloud
The Internet of Things: Information Technologies “Meet” Operational Technologies

Information Technologies Today:
1. Clouds
2. Enterprise Datacenters
3. Traditional and Embedded Endpoints
4. Networking

The Internet of Things Brings Together Information Domain and Operations Domain through:
1. Connectivity
2. Data Sharing and Analysis
3. Technology Convergence
The Future 5G networks and IoT require more virtualized, scalable, reliable, secure, real-time capable Computing and Storage at the Edge:

Fog Computing!
Mobile Edge Computing!
Real-time Edge Computing
Global Spend for Industrial IoT Relevant Industries: 2016-2020 Forecast

- Global IoT spending (CAGR) of 15.6% over the 2015-2020 forecast period, reaching $1.29 trillion in 2020
- Worldwide spending on the Internet of Things (IoT) is forecast to reach $737 billion in 2016
- In 2016 IoT spending led Industrial IoT verticals: Manufacturing ($178B), Intelligent Transportation ($78), and Utilities ($69B)


The spending includes: hw, services, sw, and connectivity
What is Fog Computing?
The missing link between Clouds and Endpoints

Fog Computing brings:

Cloud-inspired computing, storage, and networking functions closer to the data-producing sources

while integrating real-time and safety capabilities required in the OT domain

Fog Computing is the key enabler of a real convergence between IT and OT technology
Fog Computing: Motivations for a New Infrastructure Layer
By now Fog and its motivations are getting naturally accepted

1. Communications, gateway networking convergence
2. Edge data management, analytics
3. Distributed application hosting
4. Virtualization of all resources, multi-tenancy
5. Security and Privacy
6. Real-time, local control
7. Scalability
8. Reliability

Peter Levine (Andreesen&Horowitz) during Gartner keynote session last week: “the cloud computing is dead, the intelligence/processing is going down close to the things”
5G: Planning a Huge Role in the Support of Industrial IoT Applications

Adopting Important Bandwidth, Deterministic, Low Latency, Scale and Coverage Requirements (E.g., Massive IoT, Autonomous Vehicle Communications, High Reliability,...)

Key Values of 5G:
- Licensed spectrum
- Reliability
- Range of features
- Investment
- Political power

Ref: Qualcomm
Key Architectural Angles Characterizing the “Fog” and Relevant to 5G:

- IT to OT Convergence
- Hierarchical Data Management and Analytics
- Virtualized and Distributed Application Platform
- The Evolution of Control
- Decentralized Security
Fog Computing: Manifesting and Enabling the Convergence of IT and OT Technologies at the Edge

Information Technologies:
Virtualization and Multi-Tenancy, Software Management Automation, Data Analytics, Scalability, Software Defined Networking (SDN), Security and Privacy

Operations Technologies:
Real-time, Safety, Reliability, Control, Machine Connectivity and Data Acquisition, Human Machine Interface
Fog Computing: At the Convergence of IT and OT Networking Technologies – Multiple Future Roles for 5G

Information Networking Technologies:
- Ethernet, WiFi, Cellular 3/4/5G, Bluetooth LE, SDN

Operations Networking Technologies:
- Real-time capable and Safety capable Field Networking
- Industrial Wireless, IEEE TSN (Deterministic Ethernet), LoRA, PLC
Fog Computing: At the Convergence of IT and OT Networking Technologies – Multiple Options Will Compete

**Wireless Technologies:**

1. Cellular (2G/3G/4G/5G)
2. Bluetooth Low Energy (BLE)
3. LoRa (Low power, long range, low bandwidth)
4. IEEE 802.15.4 with 6T-SCCH
5. WiFi: Low Power, Deterministic, Vehicular (802.11.p)

**Wired Technologies:**

1. Deterministic Ethernet
2. Power Line Communications

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**IoT and Wireless Technologies Map**

- Distance (m)
- Data Rate (bps)

- 5G
- Cellular (5G)
- 802.15.4 (6T-SCCH)
- LoRa
- Bluetooth LE

Deterministic, Time-triggered Ethernet is based on:

1) A global notion of time
2) A communication global schedule (when to do what)

Fundamental for Industrial IoT!

Deterministic = Reliable, Very Low Jitter, even more than Low Latency

Future Standard for Automotive, Transportation, Industrial,...

Network Virtualization based on Deterministic Ethernet

- Synchronous Traffic
  - real-time control
  - safety

- Streaming
  - audio
  - video

- Standard Ethernet Traffic
  - diagnostics over IP
  - download and updates

- Guaranteed timing for hundreds of real-time control functions
- Guaranteed bandwidth even in case of excessive network loads
- Guaranteed delivery even in case of network faults

www.tttech.com
Real-Time Fog Computing Requires Deterministic Ethernet
Many Deterministic Communications Scenarios Across Distributed Real-time Applications

Can 5G Play Here?
Fog Computing as a Distributed System: Remote or Local Management of a Distributed, Federated Collection of Nodes

- Zero-Touch deployment of Fog nodes, and assets
- Application hosting and full Life Cycle Management
- Asset Management
- Management and scheduling of real-time resources
- End-to-end security management
- Fog node federation, distributed storage
Fog Computing: Supporting a Hierarchical Data Acquisition-Analysis-Control Cycle

- Learning in the Cloud and deploying simpler models in the Fog
- Fast reaction to rich local analysis
- Data objectization and reduction

Learning to simplified models

100s μsecs to mins

100s μsecs to msecs

μsecs

17
Fog Computing: Real-time Capable Virtualization to the Edge

Virtualization:

A combination of physical separation (multicore), hard, RT-NRT Virtual Board/Machine based virtualization and more lightweight Linux/Windows Container or Docker based virtualization.
Fog Computing: Enabling the Convergence of Control

Deterministic Networking and Real-time Virtualized Computing enable the Convergence of Multiple Control Functions, one step removed from the controlled Endpoints:

The Software Defined Machines! (Ref: GE)
Fog Computing: Enabling Decentralized Security
Particularly Natural for Security in a Fog Based Infrastructure

Fog Resources Can Be Used to Help Less Capable Devices, i.e.,:
- Identify
- Protect
- Isolate
- Verify
- Upgrade

A Fundamental Mediation Role
Fog Computing and 5G, Natural Partners for the Future of Key Industrial IoT Verticals:

- Industrial Automation
- Automotive and Intelligent Transportation
- Smart Grid

Motivations: Licensed spectrum, reliability, range of features, investment, ….
Industrial Automation
Starting from Automotive Body Shops and Precision Machine Floors
Fog Computing: A New Functional Layer in the Industrial Pyramid
Driving IT to OT Convergence & the Future of Control for Industrial IoT and Industry 4.0

Hierarchical, Virtuous Cycles of Data Acquisition, Analysis and Control

Enterprise Resource Planning
Manufacturing Execution System
Process Control System
Machine Control

Fog Computing: Communications, Analysis, Control and Application Hosting and Orchestration

Fieldbus-Level: Signals
Actual Production

ERP
SCADA
MES

Cloud level optimization
Local, orchestrated control based on rich local analysis
Fast, Light Endpoint Control

Feedback to production
Analysis of Production Data
Fog-Based Industrial Floor: Enabling New and Converged Functionality

Today's Functionality

- ERP/MRP System
- Manufacturing Execution System
- Cell Controller
- Machine Vision and Bar Code Reader
- Programmable Logic Controller (PLC) System
- Robotics Controller and Visualization

1) Adding New Functionality

2) Converging and Enriching Current Functionality

Data Center/Clouds

Fog Layer

1) Adding New Functionality

Cell 1

Cell N
Industrial Machine: A Complex System with Many Sensors, Actuators and Control Loops
# 3G, 4G, and 5G: Manuy Use Cases in Industrial Automation

<table>
<thead>
<tr>
<th>Use Case</th>
<th>Most Challenging Requirements</th>
<th>Value</th>
<th>Cellular Access Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell automation</td>
<td>Latency</td>
<td>0.5ms</td>
<td>5G (uMTC)</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>99.999999999</td>
<td></td>
</tr>
<tr>
<td>Automated guided vehicle</td>
<td>Mobility</td>
<td>10m/s</td>
<td>LTE, 5G</td>
</tr>
<tr>
<td></td>
<td>Reliability</td>
<td>99.999999999</td>
<td></td>
</tr>
<tr>
<td>Process Automation</td>
<td>Reliability</td>
<td>99.999999999</td>
<td>LTE, 5G, (mMTC, uMTC)</td>
</tr>
<tr>
<td>Logistics transportation tracking</td>
<td>Numb. devices Coverage</td>
<td>1000000/sqkm Global</td>
<td>LTE</td>
</tr>
<tr>
<td>Components tracking</td>
<td>Numb. devices Mobility</td>
<td>10000000/sqkm Static</td>
<td>LTE</td>
</tr>
<tr>
<td>Remote assistance</td>
<td>Reliability</td>
<td>99.999%</td>
<td>5G (uMTC)</td>
</tr>
<tr>
<td>Augmented reality</td>
<td>Data rate</td>
<td>10Gbps</td>
<td>5G (xMBB)</td>
</tr>
<tr>
<td>Remote robot control</td>
<td>Reliability</td>
<td>99.999%</td>
<td>5G (uMTC)</td>
</tr>
</tbody>
</table>

*Requirements and access technology for Industrial IoT use cases*

*Source: Ericsson Business Review, Issue 4*
Automotive and Intelligent Transportation
The Role of Fog Computing in the Automobile Evolution

Key Directions:
- Internal Networking Convergence
- Computing Virtualization
- Security
- Mobility and Multi-mode Communications (5G)
- Centralization!!!

Deterministic Ethernet Network and Consolidated, Virtualized ECU “Data Center”

Entertainment network MOST, internal WiFi

Bluetooth, Low Power WiFi, RFID

High-speed network Hi-speed CAN

Electronic Control Unit (ECU)

Central Gateway

Wheel-Sensor

Fog Node on Wheels!
The IoT Infrastructure, Fog Computing and Intelligent Transportation

Virtualized, scalable, reliable, secure, real-time capable Computing and Storage at the Edge:
Fog Computing!

Large Potential Role for 5G!
Smart Grid
The Near Future of The Smart Electrical Grid Requires Fog Computing and 5G!
Distributed Intelligence, IT and OT Convergence, Standard, Interoperable, Secure

Current State: Message Bus at Data Center

Future State: Message Bus in Field and Data Center
The Near Future of The Smart Electrical Grid Requires Fog Computing and 5G!
Distributed Intelligence, IT and OT Convergence, Standard, Interoperable, Secure

Figure 3-1: Duke Energy Distributed Intelligence Platform Node Architecture

Figure 3-3: Modular Chassis Design
The Near Future of The Smart Grid Requires Fog Computing and 5G!!
A Standardization Across USA Utilities, with Proof of Concept Deployment, has been Achieved in One Year !!!

RECOMMENDATION Approved by the RMQ Executive Committee
via Notational Ballot on February 4, 2016
For Quadrant: Retail Markets Quadrant

Requesters: RMQ OpenFMB Task Force
Request No.: 2015 Retail Annual Plan Item 9.a/R14008
Request Title: Develop model business practices to support OpenFMB architecture for interoperable data exchange between distributed power systems devices on the electric grid’s field area networks.
Brief Introduction to Nebbiolo Technologies
Nebbiolo = Grape Enjoying the Morning Fog (=Nebbia) in Northern Italy

Producing wonderful wines: Barolo, Barbaresco, Nebbiolo, Valtellina Reds
Nebbiolo Technologies is architecting and building an innovative Fog Computing Platform for IoT Solutions

and applying it, first, in the vertical of Industrial Automation

**Team:** World-class, Cisco sourced, experienced (20+ people) team surrounded by a rich ecosystem of IoT technology partners

**Investors:** KUKA Robotics, TTTech and GiTV (Tokyo, Japan VC)

**Milestones:** 7 Patents pending; Strong Traction; Production deployments and PoCs ongoing; First product released (December 2016)
Nebbiolo Technologies Fog Computing Platform Components

1. A **flexible hardware architecture** manifesting in a family of **fogNodes**

2. A rich **software distributed stack** (the **fogOS**), enabling fast, secure, flexible communications, data management and application deployment

3. An **end-to-end system management** of distributed networking and computing systems, assets, software and applications (the **fogSM**)

<table>
<thead>
<tr>
<th>Manageability</th>
<th>Secure Stack</th>
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<tbody>
<tr>
<td></td>
<td>Business Application</td>
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<tr>
<td></td>
<td>IoT Infrastructure</td>
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<td>Application hosting &amp; Orchestration</td>
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<td></td>
<td>Middleware</td>
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<td>Cloud Infrastructure</td>
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<td>Fog Infrastructure</td>
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<td>Admin Plane</td>
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<tr>
<td></td>
<td>RTOS/Kernel</td>
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<tr>
<td></td>
<td>Host OS/Hypervisor</td>
</tr>
<tr>
<td></td>
<td>Hardware (X86/Arm)</td>
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Fog System Management

Federation of fogNodes

Machines and Things
Conclusions
Conclusions

Fog Computing and 5G are Natural Partners for the Future of Industrial IoT

More Reliable, Lower Latency, Deterministic Wireless Networking is Essential for Real-time Fog Computing and its Industrial Applications!

More Collaboration and Experimentation is Required!

Let us Move Boldly, Together: The Future is Bright!
THANK YOU,
AND REMEMBER ..

ONLY THOSE WHO WILL RISK GOING TOO FAR CAN POSSIBLY FIND OUT JUST HOW FAR ONE CAN GO.

T.S. Eliot