IoT++

THE LIVING NETWORK OF EVERYTHING AND EVERYONE

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A 90’s Question:
“What happens if sensors become tiny, wireless, and self-contained?”

Smart dust

[1997, K. Pister, UC Berkeley]

... Wireless Sensor Networks
Transitioning to ...

“What Happens if Integrated Components Approach Molecular Limits and/or May Cover Complete Walls, all wirelessly networked, leading to Trillions of Connected Devices?”

The Swarm
The Swarm at The Edge of the Cloud

[J. Rabaey, ASPDAC'08]
A Foundational Transformation in Engineering

Pre-1950’s: Engineering the physical world (industrial revolutions)

1950-2000’s: Engineering abstract objects (the “cyber world”)

Post 2000: “Cyberphysical/Biological Systems” bridging the two, engaging society at large
Promise Unfulfilled For More Than Decade....

(Source: On World)
- Cost savings not yet disruptive
- Reliability
- Energy (battery life)
- Ease of use

**NO ECONOMY OF SCALE**

Stovepipes, Fragmentation, Non-interoperability, Lack of Virtualization
Living in a Smart World

It is happening!

Smart things, smart tools, smart cars, smart buildings, smart cities, smart everything ...
Internet Of Things Market To Reach $267B By 2020

B2B spending on IoT technologies, apps and solutions will reach €250B ($267B) by 2020.

By 2020, 50% of IoT spending will be driven by discrete manufacturing, transportation and logistics, and utilities

[Forbes, January 2017]
Technology as an Enabling Factor

The Smart Dust Vision
[K. Pister, UCB, 1997]

Has become a reality!

Michigan Micromote [Blaauw et al, 2014]
Technology Barriers Are Scaled

“General Purpose” low-power wireless sensor platforms

Examples: Bosch, ST Micro, TI

Bluetooth LE, ANT

Networks and network Integration
Emerging Swarm Infrastructure

Cloud-based service

IoT Gateways
- Bridge between Cloud and Swarm
- Distributed computing and data storage

The Fog*

*Term coined by F. Bonomi@Cisco
Scaling the Swarm: Open Platforms and Virtualization

Apps
- Home security/emergency
- Energy-efficient home
- Health monitoring
- Unpad

Resources
- Sensors/Input devs
- Actuators/Output devs
- Storage
- Networks
- Computing

SWARM-OS

[N. Mor 2016]
Scaling the Swarm: Open Platforms and Virtualization

21 Open Source Projects for IoT

[linux.com, september 2016]

News & Analysis
IoT Group Sets Broad Agenda
Security is an early focus for OpenFog
Rick Merritt
2/15/2017 06:16 PM EST
Post a comment

SAN JOSE, Calif. – A group of more than 50 organizations released a broad framework this week for delivering services across the Internet of Things. The OpenFog Reference Architecture aims to set a baseline for guiding work on standards and product design, starting with security.
Scaling the Swarm: The Data Deluge

What really matters: information and knowledge!

Digital data generated worldwide (in ZettaBytes)

[Data from IDC, 2016]

Phenomenal Growth of Learning-Based Approaches

[Courtesy: J. Bilmes, UW – DARPA Wait What Demo]
Scaling the Swarm: Security

Needs solution for the GROUND UP
A Very Broad Agenda

- Programming Models
- Network as the Computer
- Services
- Security / Privacy
- Closed Loop Control
- Machine Learning
- Data Analytics
- Verification / Diagnostics

[Courtesy: StarNet Terraswarm Center]
Are we done yet?

By no means!

Quest for scalable, robust, reliable and secure Swarm ongoing

Yet, increasingly the domain of industry and large consortia
Upping the Ante
Back to Original Swarm Dream

An extremely dynamic network of a huge number of connected entities
Living in a Smart **Dynamic** World

It is happening!

Smart things, smart cars, smart drones, smart robots, smarter humans, smart everything ...
The Swarm is “Evolving”: IoT++

Autonomous, VERY dynamic, yet human-centric
The Swarm is “Evolving”: IoT++

The Living Network of Everyone and Everything
Multiple Scales in Space

The Human Intranet

City and Nation Networks

The Tactile Internet *

The Industrial Internet

Similar problems, different scales

*Courtesy: G. Fettweis, UT Dresden
Multiple Scales in Time

Example: traffic management and autonomous driving

- years
- days
- minutes
- milliseconds
- seconds
What it takes ...

- Tight latency closed-loop systems
- Deterministic in function and time
- Cognitive capabilities
- Inherently secure and private
- Inherently robust and safe
More than communication

Sense → Interpret → Actuate → Control

Deterministic latencies of msecs (or below) required for some actions

[Courtesy: Texas Instruments]
Latency and Robustness
A Holistic Perspective

Providing guarantees in presence of uncertainty

Physical-Level:
Margining, Redundancy, Diversity

Meta-Level:
Estimation, Learned Knowledge, Safe Control

Extremely expensive
A big agenda with Many components

[C. Tomlin, UCB]
Case Example
Human Intranet
Humans in a Smart World

Mobiles
A limited bandwidth proposition
Wearable Tech?

5 reasons why I’m returning my Apple Watch

[PolicyGenius, 2015]
Imagine instead:

A Human Intranet

An open scalable platform enhancing human capabilities

[J. Rabaey, Pervasive. Comp., 2014]
Building on concepts such as Human++ (IMEC)
Image courtesy Y. Khan, UCB
Human Intranet – The Multiple Roles

Extrorspection

Introspection

Augmentation
Human Enhancement

Boost human input-output performance
- hybrid sensory expansion
- higher information throughput

Sonification

Information to Tactile
Human Enhancement

A direct connection to the brain

Brain-Machine Interfaces

[C. Bouton et al, Ohio State, Nature, April 2016]
It takes a Human Intranet

Closed-loop modulation at network level

In combination with various wearable sensors

The OMNI Device
[UCB, Cortera Neuro, LLNL]

Tension – Stress – ... Emotion

Skin conductance
3D accelerometer
Activity

[Jo De Boeck, IMEC, ISSCC 2011]
Realizing a Human Intranet

What it takes !?
Wearable and Unobtrusive

For sensing and energy provision

Printed oxonometry system
[Courtesy: A. Arias, UCB]

Blood oxonometry, EEG, EMG, ECG, heart rate, thermistors, motion, humidity, stress, ...

Cheap, compliant, flexible, ...

Thin Film μECoG
[Courtesy: M. Maharblz, UCB]

Wound-healing bandages

Wire batteries [Arias, UCB]
Extreme Miniaturization

Neural dust: microscopic nodes free floating in tissue to record neural activity

[DJ Seo, Neuron 2016]
Symbiotic with the biological networks

integrated information and energy distribution

Body-Area network skeleton/skin as a mesh of hubs

Local networks optimized for data/energy delivery

Mesh networks provides robustness and redundancy

Hubs as communication/computation/energy centers
Adaptive and Evolutionary
at ultra-low latencies (msec) and energy levels (mWs)

Typical BMI System
Adaptive and Evolutionary
at ultra-low latencies (msec) and energy levels (mWs)

Step          | Computation                              | Complexity
---------------|-------------------------------------------|------------
Output dimensionality reduction | O(T(K₀)²) floating point multiplications  | O(10⁹)    
System identification (“offline”) | O(4N(K + N)(K + M)M²(K + N)²) floating point multiplications | O(10¹²)    
State estimator    | O(KM) multiplications                     | O(10³)     
Feedback controller (MPC) | O(hM³N²) multiplications                 | O(10⁹)     

Typical BMI System

[Courtesy: M. Shanechi, USC]
A Symbiotic Relationship

Machine-Learning, deep nets and other brain-inspired approaches

in congruence with more traditional signal processing and control concepts
Secure and Private

Human firewall
- Unique IDs and Encryption
- Biomarkers
- Obfuscation

[Harry Potter invisibility Cloak]
IoT++: High-order bits

- A new age of information processing: ubiquitous, distributed, dynamic and VERY personal
- Redefining information technology - Stretching bounds in energy scaling, miniaturization, and distributed system design.
- Requires rethinking of system-level concepts – how to get deterministic outcomes from statistical components
- Just scratching the surface. Many more opportunities to emerge – engaging a very broad community
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