Cyber-Physical Systems (CPS)

IEEE Bombay Section and OPJU Panel

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Talk - Outline

- The Big Picture
- The Driving Technologies
- The Challenges
- Some Solutions
- Conclusions and Future Directions
The Big Picture
Smart Cities is a Solution for Urban Migration

- **Smart Cities**: For effective management of limited resource to serve largest possible population to improve:
  - Livability
  - Workability
  - Sustainability

At Different Levels:
- Smart Village
- Smart State
- Smart Country

- **Year 2050**: 70% of world population will be urban

Smart Cities - 3 Is

Instrumentation

The 3Is are provided by the Internet of Things (IoT).

Source: Mohanty ISC2 2019 Keynote
IoT → CPS → Smart Cities

Cyber Physical System (CPS)

IoT is the Backbone Smart Cities.

Source: Mohanty CE Magazine July 2016

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Cyber-Physical Systems (CPS) - 3 Cs

3 Cs of IoT - Connect, Compute, Communicate

Healthcare Cyber-Physical System (H-CPS)

Quality and sustainable healthcare with limited resources.

Source: Mohanty CE Magazine July 2016
Transportation Cyber-Physical System (T-CPS)

“The global market of IoT based connected cars is expected to reach $46 Billion by 2020.”

Source: Datta 2017, CE Magazine Oct 2017

IoT Role Includes:
- Traffic management
- Real-time vehicle tracking
- Vehicle-to-Vehicle communication
- Scheduling of train, aircraft
- Automatic payment/ticket system
- Automatic toll collection

Agriculture Cyber-Physical System (A-CPS)

**Future Farms**

Small and smart

**Farming Data**

The farm generates vast quantities of rich and varied data. This is stored in the cloud. Data can be used as digital evidence reducing time spent completing grant applications or carrying out farm inspections saving on average £5,500 per farm per year.

**Texting Cows**

Sensors attached to livestock allowing monitoring of animal health and wellbeing. They can send texts to alert farmers when a cow goes into labour or develops infection increasing herd survival and increasing milk yields by 10%.

**Survey Drones**

Aerial drones survey the fields, mapping weeds, yield and soil variation. This enables precise application of inputs, mapping spread of pernicious weed blackgrass could increasing Wheat yields by 2-5%.

**Fleet of Agribots**

A herd of specialised agribots tend to crops, weeding, fertilising and harvesting. Robots capable of microdose application of fertiliser reduce fertiliser cost by 95.9%.

**Climate-Smart Agriculture Objectives:**

- Increasing agricultural productivity
- Resilience to climate change
- Reducing greenhouse gas

Source: http://www.fao.org

**Automatic Irrigation System**

Smart Agriculture/Farming Market Worth $18.21 Billion By 2025


Source: Maurya 2017, CE Magazine July 2017
Driving Technologies
Sensor Technology – Variety of Them

Source: Mohanty ICCE 2019 Keynote
Selected IoT Communications Technology

- Bluetooth Low-Energy (BLE)
- Zigbee
- Z-Wave
- 6LoWPAN
- Thread
- WiFi
- Cellular
- NFC
- Sigfox
- Neul
- LoRaWAN

Source: https://www.rs-online.com/designspark/eleven-internet-of-things-iot-protocols-you-need-to-know-about

Computing Technology - Current and Emerging

320 trillion operations per second

SoC based Design: 30 watts of power

Source: https://www.engadget.com/2017/10/10/nvidia-introduces-a-computer-for-level-5-autonomous-cars/

Source: https://fossbytes.com/googles-home-made-ai-processor-is-30x-faster-than-cpus-and-gpus/

Source: https://www.qualcomm.com/news/onq/2013/10/10/introducing-qualcomm-zerot...processors-brain-inspired-computing

Source: https://kossbytes.com/googles-home-made-ai-processor-is-30x-faster-than-cpus-and-gpus/
Machine Learning Technology

Artificial Intelligence

Tensor Processing Unit (TPU)

IoT Use:
- Better decision
- Faster response

Source: http://transmitter.ieee.org/impact-aimachine-learning-iot-various-industries/

Source: https://fossbytes.com/googles-home-made-ai-processor-is-30x-faster-than-cpus-and-gpus/

April 2017

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Blockchain Technology
UAV – Smart City Applications

UAV Applications - 4 Categories

Data collection & surveying

Monitoring & Tracking

Temporary Infrastructure

Delivery of Goods

The Challenges
Smart City – Selected Challenges

- Safety
- Massive Scaling
- Design and Operation Cost
- Security, Privacy, and IP Protection
- Robustness
- Energy Consumption
- Architecture and Dependencies
- Creating Knowledge and Big Data

Source: Mohanty ICIT 2017 Keynote
Security Challenge - System

Power Grid Attack


Source: http://money.cnn.com/2014/06/01/technology/security/car-hack/

Source: http://politicalblindspot.com/u-s-drone-hacked-and-hijacked-with-ease/
IoMT Security – Selected Attacks

Impersonation Attacks

Eavesdropping Attacks

Smart Healthcare

Reverse Engineering Attacks

Radio Attacks

Implantable Medical Devices (IMDs) have integrated battery to provide energy to all their functions → Limited Battery Life depending on functions

Higher battery/energy usage → Lower IMD lifetime

Battery/IMD replacement → Needs surgical risky procedures

Source: Mohanty IEEE MetroCon 2019 Invited Talk
Blockchain has Many Challenges

- Lack of Scalability
- High Energy Consumption
- High Latency
- Lack of Privacy
- Limited Onchain Storage Capability
- Fake Block Generation

Blockchain Energy Need is Huge

Energy consumption for mining of 1 bitcoin

Energy for mining of 1 bitcoin

Energy consumption for each bitcoin transaction

Energy consumption of a credit card processing

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AI Security - Attacks

Attacker’s Capabilities

Access to Training Data

Get Data

Train Model

Prepare Data

Model Testing

Access to Model Training

Deploy Model

Access to Trained Model

Model Poisoning, Extraction

Model Inversion, Invasion, Impersonation

Attacker’s Goals

Source: Sandip Kundu ISVLSI 2019 Keynote.
Some Solutions
Secure Digital Camera – My Invention

Include additional/alternative hardware/software components and uses DVFS like technology for energy and performance optimization.

Security and/or Privacy by Design (SbD and/or PbD)

Our Secure by Design Approach for Robust Security in Healthcare CPS

IoMT Security – Our Proposed PMsec

Proposed Approach Characteristics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value (in a FPGA/ Raspberry Pi platform)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to Generate the Key at Server</td>
<td>800 ms</td>
</tr>
<tr>
<td>Time to Generate the Key at IoMT Device</td>
<td>800 ms</td>
</tr>
<tr>
<td>Time to Authenticate the Device</td>
<td>1.2 sec - 1.5 sec</td>
</tr>
</tbody>
</table>

We Proposed World’s First Hardware-Integrated Blockchain (PUFchain) that is Scalable, Energy-Efficient, and Fast
PUFchain: The Hardware-Assisted Scalable Blockchain

PUFchain System Model

PUFchain Working Model

PUFChain 2 Modes:
(1) PUF Mode and
(2) PUFChain Mode

Can provide: Device, System, and Data Security

Our PoP is 1000X Faster than PoW

PoP is 1,000X faster than PoW

PoP is 5X faster than PoAh

<table>
<thead>
<tr>
<th></th>
<th>PoW</th>
<th>PoAh</th>
<th>PoP</th>
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</thead>
<tbody>
<tr>
<td>Time</td>
<td>10 min in cloud</td>
<td>950ms in Raspberry Pi</td>
<td>192ms in Raspberry Pi</td>
</tr>
<tr>
<td>Power</td>
<td>3 W Power</td>
<td>5 W Power</td>
<td></td>
</tr>
</tbody>
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Energy Consumption and Latency in Communications

- IoT with Cloud: Sensor big data goes to cloud for storage and analytics – Consumes significant energy in communications network

- Connected cars require latency of ms to communicate and avoid impending crash:
  - Faster connection
  - Low latency
  - Lower power

- 5G for connected world: Enables all devices to be connected seamlessly.

Source: https://www.linkedin.com/pulse/key-technologies-connected-world-cloud-computing-ioe-balakrishnan
Eternal-Thing: Combines Security and Energy Harvesting at the Edge

Harvesting System with Physically Unclonable Function (PUF)

System-on-Chip (SoC)

Trans-receiver

Solar Cell

Sensors

Provides security while consuming only 22µW power due to harvesting.

Edge Devices and their deployment


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Smart Healthcare - Stress Monitoring & Control

Advise Examples: Specific Music, Shower, Physical Exercise, Breathing Exercise, Meditation, Yoga, …

Body Temperature

Physical Activity Monitoring Sensor

Sweat Sensor

Food Intake Monitoring Components

Various Data

Edge Deep Learning Based Stress Models

Stress-Level Detection Unit

Stress Management Unit

Wi-Fi Module

Long-Term Advise

Short-Term Advise

Cloud Deep Learning Based Stress Models

Internet Cloud

Automated Stress Level Detection and Management

Sensor | Low Stress | Normal Stress | High Stress
---|---|---|---
Accelerometer (steps/min) | 0-75 | 75-100 | 101-200
Humidity (RH%) | 27-65 | 66-91 | 91-120
Temperature °F | 98-100 | 90-97 | 80-90

iGLU: Accurate Noninvasive Glucose Level Monitoring and Insulin Delivery

Continuous Glucose Monitoring

Privacy-Assured Health Data Storage

Security-Assured System

Cloud Storage

Hospital

Doctor

Display of Parameters

Insulin Secretion

Artificial Pancreases System (APS)

Near Infrared (NIR) based Noninvasive, Accurate, Continuous Glucose Monitoring

Conclusions
Conclusions

- Energy requirements and security vulnerability are important challenges in Cyber-Physical Systems (CPS).
- Various elements and components of CPS including Data, Devices, System Components, AI need security.
- Both software and hardware based attacks and solutions are possible.
- Security in H-CPS, E-CPS, and T-CPS, etc. can have serious consequences.
- Existing security solutions have serious overheads and may not even run in the end-devices (e.g. a medical device) of CPS/IoT.
- Security-by-Design (SbD) or Hardware-Assisted Security (HAS) advocate features at early design phases, no-retrofitting.
CPS Design - Multi-Objective Tradeoffs

Source: Mohanty ICCE 2019 Keynote
Security by Design (SbD) and/or Privacy by Design (PbD)

Embedding of security/privacy into the architecture (hardware+software) of various products, programs, or services.

Retrofitting: Difficult → Impossible!

Source: https://teachprivacy.com/tag/privacy-by-design/
Thank You !!!

Slides Available at: http://www.smohanty.org

Hardwares are the drivers of the civilization, even softwares need them.