Research Centre of Excellence
Faculty of Engineering
Internet of Things (IoT): Shaping the Network of the Future

Dr. Shaiful Jahari Hashim
Contents

• IoT Technology Overview
• UPM WiPNET IoT Experiences
• Future Networks for IoT
• Conclusions
IoT Technology Overview
Technology

• The most profound technologies are those that are disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it ....

- Mark Weiser 1991
Internet Definition

• The **Internet** is the global system of interconnected computer networks that use the Internet protocol suite (TCP/IP) to link devices worldwide.

• It is a *network of networks* that consists of private, public, academic, business, and government networks of local to global scope, linked by a broad array of electronic, wireless, and optical networking technologies.

Source: https://en.wikipedia.org/wiki/Internet
IoT Definition

- The **Internet of things (IoT)** is the inter-networking of physical devices embedded with electronics, software, sensors, actuators, and network connectivity which enable these objects to collect and exchange data.
  - “things” as an *inextricable mixture of hardware, software, data and service.*
  - “things” include humans

Source: https://en.wikipedia.org/wiki/Internet_of_things
IoT Definition (continue)

“Anything Can Be Connected, Will Be Connected”
The Variety of IoT

• It is a set of discrete applications that have highly divergent requirements:
  • Radius of connectivity varies from mm to kilometers
  • Bandwidth varies from bits to gigabits per second
  • Data volumes vary from bytes to petabytes
  • Connectivity models may be push or pull
  • Connectivity may be ad-hoc relays to dedicated wired
  • Transactions may be unicast, multicast or anycast in nature
  • Applications include sensing and reporting, command and control, adaptation and interfacing

Source: “Some thoughts on IoT”, Geoff Huston, Chief Scientist, APNIC
IoT Technology Roadmap

Technology roadmap: The Internet of Things

- Miniaturisation, power-efficient electronics, and available spectrum
- Teleoperation and telepresence: Ability to monitor and control distant objects
- Ubiquitous Positioning
- Vertical-Market Applications
- Supply-Chain Helpers
- Locating people and everyday objects
- Surveillance, security, healthcare, transport, food safety, document management
- Demand for expedited logistics
- Cost reduction leading to diffusion into 2nd wave of applications
- RFID tags for facilitating routing, inventorying, and loss prevention

Source: SRI Consulting Business Intelligence
IoT is Big Part of 5G: Use Cases

- Broadband media everywhere
- Smart vehicle and transport
- Critical services and infrastructure control
- Critical control of remote devices
- Human machine interaction
- Sensors networks

Source: https://www.ericsson.com/en/5g/use-cases
New IoT Framework

Response/Feedback (Autonomy/Adaptive/Real-time)

Resource Management (Bare Metal/OS/Distributed System)

Decision Support/Analysis/Analytics (Algorithm/Intelligence/Data mining)

Storage/Memory/Big Data (Database/File System/LUT)

Processing/Acquisition/Control/Communication (CPU/IO/Sensor/Actuator/Transceiver)

Physical (Raw Data/Things/Environment)
IoT Device Types

• Constrained devices with limited resources
  • Low bandwidth
  • Low cost
  • Limited processing and memory
  • Battery powered

• Unconstrained devices with ample resources
Smart Cities in Malaysia

**Emerging market**
- Rapid growth in urban population
- Gaps in provision of education, healthcare, internet service

**Advanced market**
- Aging population
- High level of education, healthcare, internet service
- Environmental awareness
- Well established but congested public transport

*Source Netherland’s MoEA*
UPM WiPNET IoT Experiences
UPM WiPNET IoT Experiences

• Precision agriculture
• Slope monitoring
• Bridge monitoring
Precision Agriculture

Rockmelon: Taman Kekal Pengeluaran Makanan (TKPM) Besut, Terengganu
Fertigation Controller
Network Topology

JKR SITE OFFICE (JKR KINTA)

MONITORED SLOPE

450MHz
1.5km
9.2kbps
Penang Bridge Monitoring

- Sensor nodes divided into 4 clusters:
  - Cluster A: Pillar 82
  - Cluster B: Pillar 86
  - Cluster C: P1NE cable stays
  - Cluster D: P1NE pillar
Lessons Learnt from IoT Perspectives

• Controlling is more useful than just monitoring
• Some areas in Malaysia simply do not have Internet or any available connections (and probably never will)
• Sending persistent sensor data over cellular network can be problematic
• Most of the times star topology is all you need
Future Networks for IoT
Future Networks for IoT

• Future Networks
• Future Higher-level Network Protocols
Future Network for IoT (continue)

“IP Over Everything, Everything Over IP” - Anonymous

https://xkcd.com/927
Future Networks for IoT

• Long Range Wireless
  • Cellular
  • Wireless local loop
• Short Range Wireless
  • Bluetooth
  • IEEE 802.15.4
• Satellites
  • Geo Synchronous Orbit (GSO)
  • Non Geo Synchronous Orbit (NGSO)
• Ad Hoc Wireless
• Wired
  • Fieldbus
Cellular Network

- 3GPP standards
- CAT NB-1 (NB-IoT)
- CAT M1 (LTE-M)
LTE-M/NB-IoT Chip

• Sequans Communications
  • Monarch and Monarch SX

• Altair Semiconductors - Sony
  • ALT1250

• Qualcomm
  • MDM9206

• ARM - Soft Bank
  • IPs
SoC Monarch SX: LTE-M & NB-IoT

LTE Applications By Category

- **Lighting**
- **HVAC Control**
- **Parking Control**
- **Industrial Monitor**
- **Agriculture Monitor**
- **Smoke Detectors**
- **Pollution Monitors**
- **Electric Meter**
- **mPERS**
- **Personal & Pet Trackers**
- **Patient Monitor**
- **Asset Trackers**
- **Fitness Bands**
- **Kids Watch**
- **Smoke Detectors**
- **PVAC Control**
- **Sensors**
- **Wearables/Meters**
- **IoT Aggregators**
- **Data Devices**
- **IoT Gateways**
- **Connected CE Devices**
- **Connected Healthcare**
- **Enterprise PDA**
- **Telematics**
- **Digital Signage**
- **Alarm Panel**
- **Retail Kiosk/ATM**
- **POS Terminal**
- **In-Car Hotspot**
- **In-Car Infotainment**
- **Network Bridges**
- **Routers**
- **Gateways**
- **Network Bridges**
- **In-Car Infotainment**
- **Video Surveillance**

Source: http://www.sequans.com/
Wireless Local Loop Networks

• LoRa
  • Sub 1 GHz
  • Thousands devices for one gateway
  • Tens of kilometers range
  • CSS modulation
  • 0.3 to 50 kbps
  • Development kit for one gateway and two nodes USD$499!

• 802.11 ah (Wi-Fi HaLow)
  • Sub 1 GHz
  • Thousands devices for one gateway
  • 1 km range
  • OFDM modulation (based on 802.11 a/g)
  • Up to 100 kbps
LoRa/LoRaWAN Protocols Stack

Source: https://medium.com/iotforall/a-primer-for-lora-lorawan-7658fd9f9620
LoRa/LoRaWAN Network Topology

Concentrator /Gateway

Network Server

Application Server

asset tracking

gas monitor

water meter

trash container

vending machine

fire detection

LoRa® RF LoRaWAN™

TCP/IP SSL LoRaWAN™

TCP/IP SSL Secure Payload

AES Secured Payload Application Data
Real World Example

• Deployment of LoRa technology gateways creates IoT network coverage for most of Munich (310.43 km\(^2\)/119.86 square miles)!

Short Range Wireless

• Bluetooth
  • Based on IEEE 802.15.1

• IEEE 802.15.4
Bluetooth Standard Protocol
# Bluetooth Versions

<table>
<thead>
<tr>
<th>Bluetooth Version</th>
<th>Maximum Speed/ Mbps</th>
<th>Maximum Range/ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0</td>
<td>25</td>
<td>10</td>
</tr>
<tr>
<td>4.0</td>
<td>25</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
<td>240</td>
</tr>
</tbody>
</table>
### 802.15.4

**Options for Frequency Assignments**

<table>
<thead>
<tr>
<th>Geographical regions</th>
<th>Europe</th>
<th>Americas</th>
<th>Worldwide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency assignment</td>
<td>868 to 868.6 MHz</td>
<td>902 to 928 MHz</td>
<td>2.4 to 2.4835 GHz</td>
</tr>
<tr>
<td>Number of channels</td>
<td>1</td>
<td>10</td>
<td>16</td>
</tr>
<tr>
<td>Channel bandwidth</td>
<td>600 kHz</td>
<td>2 MHz</td>
<td>5 MHz</td>
</tr>
<tr>
<td>Symbol rate</td>
<td>20 ksymbols/s</td>
<td>40 ksymbols/s</td>
<td>62.5 ksymbols/s</td>
</tr>
<tr>
<td>Data rate</td>
<td>20 kbits/s</td>
<td>40 kbits/s</td>
<td>250 kbits/s</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
<td>BPSK</td>
<td>Q-QPSK</td>
</tr>
</tbody>
</table>

802.15.4 (continue)

• CSMA-CA
  • multiple users or nodes access the same channel at different times without interference
  • most transmissions are short packets that occur infrequently for a very low duty cycle (<1 %)

• DSSS and FHSS (802.15.4e)

• Transmission power
  • 0.5 mW (-3dBm) - minimum
  • 1 mW (0 dBm) - typical
  • 100 mW (20 dBm) - maximum
802.15.4 Network Topology Support

a. Star

Remote transceiver nodes

Central coordinator node

b. Peer-to-peer

Remote transceiver nodes

Central coordinator node

All nodes are transceivers

Central coordinator node

Mesh

A B C D E F G

Correct

Wrong
Short Range Wireless Networks

- ZigBee,
  Wireless HART (IEC 62591)

- CoAP
- Thread + 6LowPAN
- IEEE 802.15.4
Short Range Wireless Networks Standards Comparison*

*Z-Wave is based on ITU-T G.9959 (<1 GHz) not 802.15.4

Satellite Network

• Truly global network
• Ship/Vessel tracking
• Flight tracking
  • In 2016 UN announces real-time flight tracking rules on the 2nd anniversary of MH370 disappearance

https://www.icao.int/safety/globaltracking/Pages/GADSS-Update.aspx
Satellite Network Operator

• Geo Synchronous Orbit (GSO) satellites operator
  • Inmarsat
  • Thuraya

• Non-Geo Synchronous Orbit (NGSO) satellites operator
  • Iridium
  • Intelsat
  • SES
  • Telesat
  • Sky Perfect- JSAT
  • Thuraya
Inmarsat’s IP Based M2M

**BGAN M2M satellite service** is designed for unmanned equipment communication (via an Internet connection) with costs of 1 to 2 cents per Kilobyte transferred (2 MB plan – USD24)

Source: http://www.groundcontrol.com/BGAN_M2M.htm
Inmarsat’s BGAN Satellite Coverage Map
Ad Hoc Network

• RFID
  • Forest tree inventory

• Energy Harvesting and Backscattering
  • UAV based environmental monitoring
Fieldbus

- **Fieldbus** is the name of a family of industrial computer network protocols used for real-time distributed control
- Standardized as **IEC 61158**
  - Part 1: Overview and guidance for the IEC 61158 series
  - Part 2: Physical Layer specification and service definition
  - Part 3: Data Link Service definition
  - Part 4: Data Link Protocol specification
  - Part 5: Application Layer Service definition
  - Part 6: Application Layer Protocol specification
- **AS-Interface, CAN, EtherCAT, FOUNDATION fieldbus, Interbus, LonWorks, Modbus, Profibus, BITBUS, CompoNet, SafetyBUS p, RAPIEnet**
Future Higher-level Network Protocols
# Future Higher-level Network Protocols

<table>
<thead>
<tr>
<th>Protocol</th>
<th>CoAP</th>
<th>XMPP</th>
<th>RESTful HTTP</th>
<th>MQTT</th>
<th>ZeroMQ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport</strong></td>
<td>UDP</td>
<td>TCP</td>
<td>TCP</td>
<td>TCP</td>
<td>UDP</td>
</tr>
<tr>
<td><strong>Messaging</strong></td>
<td>Request/Response</td>
<td>Publish/Subscribe</td>
<td>Request/Response</td>
<td>Publish/Subscribe</td>
<td>Publish/Subscribe</td>
</tr>
<tr>
<td><strong>2G, 3G, 4G Suitability (1000s nodes)</strong></td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Fair</td>
</tr>
<tr>
<td><strong>LLN Suitability (1000s nodes)</strong></td>
<td>Excellent</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
<td>Fair</td>
</tr>
<tr>
<td><strong>Architecture</strong></td>
<td>Tree</td>
<td>Client Server</td>
<td>Client Server</td>
<td>Tree</td>
<td>P2P</td>
</tr>
<tr>
<td><strong>Compute Resources</strong></td>
<td>10Ks RAM/Flash</td>
<td>10Ks RAM/Flash</td>
<td>10Ks RAM/Flash</td>
<td>10Ks RAM/Flash</td>
<td>10Ks RAM/Flash</td>
</tr>
<tr>
<td><strong>Success Stories</strong></td>
<td>Utility Field Area Networks</td>
<td>Remote management of consumer white goods</td>
<td>Smart Energy Profile 2 (premise energy management, home services)</td>
<td>Extending enterprise messaging into IoT applications</td>
<td>CERN</td>
</tr>
</tbody>
</table>

Web and IoT Protocols Comparison

**Web**
- XML
- HTTP
- TLS
- TCP
- IPv6

- Inefficient content encoding
- Huge overhead, difficult parsing
- Requires full Internet devices

**Internet of Things**
- Web Objects
- CoAP
- DTLS
- UDP
- 6LoWPAN

- Efficient objects
- Efficient Web
- Optimized IP access

Source: https://www.micrium.com/iot/internet-protocols/
6LowPAN

- IPv6 Over Low Power Personal Area Network
- Encapsulation and header compression mechanisms that allow IPv6 packets to be sent and received over IEEE 802.15.4 based networks
- A simple low throughput wireless network comprising typically low cost and low power devices
- Devices in the network typically work together to connect the physical environment to real world applications, e.g. WSN
- Common topologies include – star, mesh, and combinations of star and mesh

Source: 6LoWPAN Overview, Assumptions, Problem Statement & Goals, Nandu Kushalnagar et. al
Shape of Future Networks for IoT?

<table>
<thead>
<tr>
<th>VSCP</th>
<th>CoAP</th>
<th>MQTT</th>
<th>HTTP</th>
<th>ZeroMQ</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UDP with DTLS</td>
<td>TCP with TLS</td>
<td>ICMP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IPv6 with 6LowPAN/etc*</td>
<td>IPv6 with 6LowPAN/etc*</td>
<td>IPv6 with 6LowPAN/</td>
<td>etc*</td>
</tr>
<tr>
<td>LoRaWAN</td>
<td>Fieldbus</td>
<td>802.14.5</td>
<td>LTE</td>
<td>Satellite MAC</td>
</tr>
<tr>
<td>LRW**</td>
<td>Wired</td>
<td>SRW***</td>
<td>LRW</td>
<td>LRW</td>
</tr>
</tbody>
</table>

*6LowPAN :IPv6 over 802.15.4 (RFC 6282)
IPv6 over Ethernet (RFC 2462)
IPv6 over PPP (RFC 5072)
IPv6 over Bluetooth BLE (RFC 7668)
**LRW: Long Range Wireless
***SRW: Short Range Wireless
Conclusions

• Internet for human’s communication is a special case, Internet for things or IoT is a general case
• Do not forget the “I” of the IoT to avoid re-inventing the wheels
• For long range network satellite is super expensive, cellular can be expensive and wireless local loop is the most cost effective
• We need to open up **full 902 – 928 MHz** for ISM bands thus IoT can proliferate and prosper in Malaysia
• IoT networks is enabler for a better future together with Industrial IoT (IIoT) and Industry 4.0
Bibliography

• National IoT Strategic Roadmap, MIMOS Berhad, 2015
• Smart Cities in Malaysia, Netherland Ministry of Economic Affair, 2012
• WSN Based Precision Agriculture, Final Report, KKMM, 2013
• WSN Based Slope Monitoring, Final Report, KKMM, 2013
• WSN Based Critical Structure and Infrastructure Monitoring, Final Report, KKMM, 2013