Mesh network technologies for industrial applications

TOSHIBA
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Introduction to TREL

TREL, Toshiba Research Europe Limited,
What is Toshiba Corp. doing in Business

Infrastructure system

Energy system

Semiconductor Supplier

Industrial IOT solutions
Corporate Research and Development

R&D Structure in Japan and Overseas has covered wide-range Biz portfolio

Toshiba Software (India) Private Limited
Toshiba Software Development (Vietnam) Co., Ltd.
Toshiba (China) Co., Ltd. Research and Development Center
Toshiba America Research, Inc.

Toshiba Electronics Europe GmbH
Toshiba Research Europe Ltd. (Cambridge)

Corporate-level Research centers
- Corporate Research & Development Center
- Corporate Manufacturing Engineering Center
- Power and Industrial Systems Research and Development Center

Development Centers of in-house Companies
- IoT Technology Center
- Power and Industrial Systems Research and Development Center
- Center for Semiconductor Research & Development
TREL activities in Bristol and Cambridge

Wireless Network
- Control
  - Reliable protocol
  - Real-Time Topology adaptive
- Infrastructure monitoring
- Energy
- Failure prognosis protocol
- Wireless Networks

Signal Processing
- Hybrid Coupler
  - TX Signal RX Signal
  - Self Interference Loop
  - SPI Interface
  - DSP and FPGA Processor Board (AMC-2C6670)
  - Digital Interface

Quantum Information
- power generation
- hospital
- transport
- building & home management systems

AI for Speech and Video recognition
- RECAIUS
- RF Board (AMC-RF2X2)
- Digital Interface
Wireless Network beyond industry 4.0
Wireless Portfolio regarding Mesh Network

Mesh Network extend distance due to collaborating with each other

- **Bit Rate**: 250K bit/s
- **Configuration**: multi-hops
- **Distance**: over 1 km
- **Scalability**: up to 100 or 1,000 nodes for one Concentrator
- **Regulatory**: IETF, IEEE802.15.4, BT, Mesh!
Dependable Industrial Wireless

From monitoring to control

Industrial Monitoring
• Monitoring of plant and remote assets for proactive maintenance

Industrial Control
• Process automation: Hydroelectric plants
• Factory automation: Assembly lines

Remote Operation
• Construction sites, mining, harbors, etc.
• Hazardous environments e.g., nuclear reactors,
• Remote driving

IoT: Massive Sensing

Ubiquitous: Steering & Control

Haptics/ Tactile Internet
• Tele-surgery
• Tele-diagnostics

2017 2019 2021 2023

Industry 4.0
Connected and AI
✓ Wired connected
✓ Uniformed analysis
✓ Centralized

Beyond Industry 4.0
Wireless, Virtual, Distributed, Mobile in Robotics Autonomous System Networks
☐ Massive wireless network
☐ Specialized/customized automatically
☐ Distributed/Self-organized

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Large-scaled mesh network

ETSI - 6TiSCH Interoperability Event – 2017, 2018
Massive Monitoring Applications

Large-scaled network with over 1,000 nodes

Data collection over 10 km range area and recognition function in a centre
- Smart meter / Smart city sensing
- Infrastructure monitoring
- Data collection and predictive maintenance at shop/warehouse

City Noise Monitoring

Pollution and Air Quality

City/Retailer/Logistic Operation Centre

Smart meter

Warehouse data

Infrastructure monitoring

Cloud
Technology challenges in Mesh Network

Scheduling considering Radio propagation performance, battery life, relay times ...

**Multipath Fading**

0% reliability

100% reliability

**Interference**

Need to avoid them
Scheduling steps to realize mesh network

1. Routing Algorithm for Lower Power, Lossy Networks

2. Confirming multi-hop traffic information

3. Scheduling algorithm

Resource Allocation Optimization in Time slot and Channel offset, “TSCH; Time Synchronized Channel Hopping”

Refer to IEEE802.15.4, 4e, IETF 6TiSCH
Large-scaled mesh performance for longer life

battery life of nodes can be doubles along communication round

Network Partitions happen

Applying data aggregation at node near Concentrator

Standardized scheduling

Our scheduling
Field Trial Test with Bristol City Council

Mesh performance in the field, Applying multi radio for reliability improvement

An array of sensors such as light, temperature, humidity, air quality, noise, spectrum usage etc. & Short range for Mesh and long range radio communication interfaces

32 nodes covering major part of the city centre of Bristol, Planning to evaluate mesh against long range radio,
Ultra low latency mesh network
Wireless Control Applications

Ultra low latency / high reliable connections

- **Closed-Loop Control**
  - 1-2 ms
  - 99.99999%

- **Open-loop Control**
  - 5-10 ms
  - 99.999%

- **50 ms**
  - 99.9%

- **Remote Operation Haptics**
  - 1-2 ms
  - 99.99999%

- **alarms & control signals dissemination**

- **Mobile control**

- **Factory automation**

- **Factory automation**

- **Wireless Control Applications**
Providing low-latency connections for all nodes,

**Concurrent Transmissions protocol, ‘Flooding’**

Design target; designing MAC layer with Bluetooth PHY layer reliability of 99.999% or more with over 100 nodes

**Merit**
- No need for complex routing protocols
- No complex scheduling
- Can support unpredictable traffic volumes

**Concern**
- ✓ Trade-offs among latency, reliability and energy efficiency
- ✓ Sensitive to high-density nodes
Concurrent Transmissions based Flooding

Source initiates a flooding to send a packet
Concurrent Transmissions based Flooding

Nodes receive and synchronise to send a packet
Concurrent Transmissions based Flooding

Send a packet at the same time at each node which received the packet.
Concurrent Transmissions based Flooding

Nodes receive packets sent at the same time

Although multi-path fading and co-channel interference happens in RF domain,

Constructive Interference in data domain

Capture Effect due to demodulation scheme
Concurrent Transmissions based Flooding

Nodes receive packets sent at the same time

Repeat this flow up to pre-set re-transmission times,

The important factor is how quick each node can re-send the packet, which leads reliability performance.
Evaluation of flooding solution

Experimental setup

Performance Metrics

- **Reliability**: % of packets against which the client received the reply from the nodes
- **Latency**: The duration between the client Tx-packet front-edge and the received packet back-edge of nodes

HW: nRF52840 Preview DK
SW: nRF5 SDK for Mesh v0.10.0-alpha
Comparison in reliability against standardized BT

Conditions:
- Packet length = 13 bytes (10B payload + 3B header)
- 4 re-transmission attempts

Standardized BT mesh

flooding

Reliability [\%]

Reliability : % of packets against which the client received the reply from the nodes

Higher reliability has been achieved
Comparison in latency against standardized BT

Conditions: Packet length = 13 bytes (10B payload + 3B header)
4 re-transmission attempts

Latency: The duration between the client Tx-packet front-edge and the received packet back-edge of nodes

Latency: 2 orders of magnitude better in latency
## Comparison against standardized BT

<table>
<thead>
<tr>
<th></th>
<th>BT mesh</th>
<th>Our designed flooding</th>
<th>Our designed another one</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protocol</td>
<td>Bluetooth PHY + Bluetooth LL + Mesh Stack</td>
<td>Bluetooth 4.0/5.0 PHY/HW + Proprietary stack ( fully bottom-up design)</td>
<td></td>
</tr>
<tr>
<td>Latency</td>
<td>250-400 msec</td>
<td>5-30 msec depending on packet size</td>
<td>&lt; 10 msec # for closed-loop control</td>
</tr>
<tr>
<td>Reliability</td>
<td>99 %</td>
<td>&gt; 99.999 %</td>
<td></td>
</tr>
<tr>
<td>Scalability</td>
<td>100 – 130 devices / 7 devices per master device</td>
<td>up to 100 -130 devices / large number of devices per master device</td>
<td></td>
</tr>
<tr>
<td>Interference</td>
<td>Can use only 3 advertising channels at maximum speed of 1Mbps</td>
<td>Can exploit all (40 BLE/80 BT) channels at maximum speed of 2Mbps (Bluetooth 5.0)</td>
<td></td>
</tr>
</tbody>
</table>

available to apply for open-loop toward closed-loop control
Summary

Mesh network has high potential beyond cellular

- Mesh network is expected in industrial IoT applications
  - Covering wide area to be connect to cloud
  - Massive Monitoring
  - Control with open-loop
  - Control with closed loop
  - Reducing operational costs

- Next technology topics toward beyond industry 4.0
  - Latency
  - Reliability
  - Scalability

  Aiming to replace wired connections with wireless connections,
Thank you