6LoWPAN
IPv6 para WSN

Carlos Taffernaberry
UTN - Mendoza - Argentina
carlos.taffernaberry@gridtics.frm.utn.edu.ar
Outline

• Introduction to 6LoWPAN
• The 6LoWPAN Features and Format
• Neighbor Discovery
• Application Layer
• Implementing 6LoWPAN
Introduction
Internet of Things

- A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communications capabilities.

- This infrastructure includes existing and evolving Internet and new network developments.

- It will offer specific object-identification, sensor and connection capability as the basis for the development of independent federated services and applications.

- These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability.
Internet of Things
Scope

Core Internet
Million nodes

Fringe Internet
Billion nodes

- Building automation
- Smart metering
- Industrial automation
- Logistics
- Transportation
- Personal sensors
- Phones
Internet of Things
Challenge I - Interconnection

Wires are too expensive
- Electrical wall socket + installation = $50
- Cat5 socket + installation = $150
- 1 Trillion nodes >> 1000 GDP Argentina

Wireless ? …. -> WSN

<table>
<thead>
<tr>
<th>Technology</th>
<th>Range</th>
<th>Speed</th>
<th>Power Use</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wifi</td>
<td>100 mts.</td>
<td>10100Mb/s</td>
<td>High</td>
<td>$$$</td>
</tr>
<tr>
<td>Bluethoot</td>
<td>10-100 mts.</td>
<td>1-3 Mb/s</td>
<td>Medium</td>
<td>$$</td>
</tr>
<tr>
<td>202.15.4</td>
<td>10 – 100 mts.</td>
<td>0.25Mb/s</td>
<td>Low</td>
<td>$</td>
</tr>
</tbody>
</table>
Evolution of Wireless Sensor Networks

- **Price**
  - 1980s: Any vendor

- **Cabling**
  - 1980s: Cables

- **Scalability**
  - 2006: ZigBee and WHART
  - 2009 ->: 6lowpan ISA100

- **Proprietary radio + network**
  - 1980s: Z-Wave, prop. ISM etc.

- **ZigBee**
  - 2006: Open development and portability

- **6lowpan Internet**
  - 2009 ->: ZigBee and WHART

- **Increased Productivity**
  - 2000: Complex middleware

- **Vendor lock-in**
  - 2000: Increased Productivity
Challenge of IoT II

Hard to implement in embedded devices:

- **Power and duty-cycle**: Battery-powered wireless devices need to keep low duty cycles.
- **Reliability**: Standard Internet protocols are not optimized for low-power wireless and lossy networks.
- **WebServices**: Internet services today rely on webservice, mainly using the transmission control protocol (TCP).
- **Management**: Management with SNMP or web services.
- **Not enough addresses**: for assign to all IoTnodes. \((2^{32})\)
Internet (v4) Regional Registry Exhaustion
Addresses Challenge

IANA Unallocated Address Pool Exhaustion: 03-Feb-2011
"Exhaustion" when the pool of available addresses in each RIR reaches the last /8 threshold.
IP next generation
IPv6

Some Features:
Address space: 128 bits ($2^{128}$)

$3.4 \times 10^{38} = 340282366920938463463374607431768211456$ addr.

There are only $\sim 10^{25}$ grains of sand on the earth
Let’s settle for a trillion objects on the net.

Fix size Header

No fragmentation in the path
Extensibility by adding extension header

Unicast, Multicast y Anycast (NO Broadcast)

Stateless and stateful address autoconfiguration
Challenge of IoT III

Hard to implement in embedded devices:

- **Frame size**: Current Internet protocols require links with sufficient frame length (minimal IPv6 MTU 1280).

- **Multicast**: Wireless embedded radio technologies do not typically support multicast (IPv6 ND requires multicast).
Benefits of 6LoWPAN Technology
IPv6 over Low-Power Wireless Personal Area Networks

- Low-power RF + IPv6 = The Wireless Embedded Internet
  - 6LoWPAN makes this possible

- The benefits of 6LoWPAN include:
  - Open, long-lived, reliable standards
  - Easy learning-curve
  - Transparent Internet integration
  - Standard socket api
  - Network maintainability
  - Global scalability
  - End-to-end data flows
  - Use of existing Internet infrastructure
What is 6LoWPAN?

- IPv6 over Low-Power wireless Area Networks
- Defined by IETF standards
  - RFC 4919, 4944 (problems, format)
  - RFC 6282, 6775 (compression, nd)
  - RFC 6606 (routing)
6loWPAN Features

- Useful with low-power link layers such as IEEE 802.15.4, narrowband ISM, power-line communications and Bluetooth
- Support for e.g. 64-bit and 16-bit 802.15.4 addressing
- Fragmentation
  - 1280 byte IPv6 MTU -> 127 byte 802.15.4 frames
- Efficient header compression
  - IPv6 base and extension headers, UDP header
- Network autoconfiguration using neighbor discovery
- Unicast, multicast and broadcast support
  - Multicast is compressed and mapped to broadcast
- Support for IP routing (e.g. IETF RPL)
- Support for use of link-layer mesh (e.g. 802.15.5)
The 6LoWPAN Features and Format
Architecture
Architecture

- LoWPANs are stub networks (no transit networks)
- Simple LoWPAN
  - Single Edge Router
- Extended LoWPAN
  - Multiple Edge Routers with common backbone link
- Ad-hoc LoWPAN
  - No route outside the LoWPAN
- Internet Integration issues
  - Maximum transmission unit
  - Application protocols
  - IPv4 interconnectivity (transition)
  - Firewalls and NATs
  - Security

IPv6-LoWPAN Router Edge Stack
The 6LoWPAN Format

- 6LoWPAN is an adaptation header format
  - Enables the use of IPv6 over low-power wireless links
  - IPv6 Fragmentation
  - IPv6 header compression
  - UDP header compression
## Dispatch

First byte of the Payload

(http://www.iana.org/assignments/6lowpan-parameters/)

<table>
<thead>
<tr>
<th>Bit Pattern</th>
<th>Header Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 xxxxxxx</td>
<td>NALP - Not a LoWPAN frame</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>01 000000</td>
<td>Reserved as a replacement value for ESC</td>
<td>[RFC6282]</td>
</tr>
<tr>
<td>01 000001</td>
<td>IPv6 - uncompressed IPv6 Addresses</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>01 00010</td>
<td>LOWPAN_HC1 - compressed IPv6</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>01 000011 to 01001111</td>
<td>reserved for future use</td>
<td></td>
</tr>
<tr>
<td>01 010000</td>
<td>LOWPAN_BC0 - broadcast</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>01 010001 to 01011111</td>
<td>reserved for future use</td>
<td></td>
</tr>
<tr>
<td>01 1xxxxx</td>
<td>LOWPAN_IPHC</td>
<td>[RFC6282]</td>
</tr>
<tr>
<td>10 xxxxxx</td>
<td>MESH - Mesh header</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>11 000xxx</td>
<td>FRAG1 -- Fragmentation Header (first)</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>11 001000 to 11011111</td>
<td>reserved for future use</td>
<td></td>
</tr>
<tr>
<td>11 100xxx</td>
<td>FRAGN -- Fragmentation Header (subseq)</td>
<td>[RFC4944]</td>
</tr>
<tr>
<td>11 101000 to 11111111</td>
<td>reserved for future use</td>
<td></td>
</tr>
</tbody>
</table>
Fragmentation

- IPv6 requires underlying links to support Minimum Transmission Units (MTUs) of at least 1280 bytes.
- IEEE 802.15.4 leaves approximately 80-100 bytes of payload!
- RFC4944 defines fragmentation and reassembly of IPv6
- The performance of large IPv6 packets fragmented over low-power wireless mesh networks is poor!
  - Lost fragments cause whole packet to be retransmitted!
  - Low-bandwidth and delay of the wireless channel
  - 6LoWPAN application protocols should avoid fragmentation
  - Compression should be used on existing IP application protocols when used over 6LoWPAN if possible
## Fragmentation

### Initial Fragment

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>datagram_size</th>
<th>datagram_tag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+-----------------</td>
<td>---------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+-----------------</td>
</tr>
</tbody>
</table>

### Following Fragments

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>datagram_size</th>
<th>datagram_tag</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+-----------------</td>
<td>---------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+-----------------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>datagram_offset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+-----------------</td>
</tr>
</tbody>
</table>

IP Header Compression (HC1 and HC2)

No gzip techniques
No end to end technique – IP addr is needed in every route
Stateless compression

C = Class and Flow Label
SAE/DAE = Source/Destination Address Encoding
NH = Next Header
S/D = Source/Destination Port Compression (61616 + 16)
L= whenever the length is compressed
Never Compressed Hop Limit and UDP Checksum
6LoWPAN Headers

- Orthogonal header format for efficiency
- Stateless header compression
Neighbor Discovery
IPv6 Neighbor Discovery

• IPv6 is the format - ND is the brains
  – “One-hop routing protocol” defined in RFC4861
• Finding Neighbors
  – Neighbor Solicitation / Neighbor Advertisement
• Finding Routers
  – Router Solicitation / Router Advertisement
• Stateless Address Autoconfiguration using NS/NA
  – Detecting Addresses Duplication (DAD) using NS/NA
• Neighbor Unreachability Detection (NUD) using NS/NA
• Statefull DHCPv6 may be used in conjunction with ND
• Requirements:
  – Link-layer Multicast
  – Transitive relation between Neighbor
Devices must be awake all the time !!!
The Whiteboard

- The whiteboard is used in the LoWPAN for:
  - Duplicate address detection for the LoWPAN (= prefix)
  - Dealing with mobility (Extended LoWPANs)
  - Locating nodes
Typical 6LoWPAN-ND Exchange
Application Formats and Protocols
Introduction

• The **processes** of applications communicate over IP using an Internet Socket approach
• 6LoWPAN also uses the same Internet Socket paradigm
• Application protocols used with 6LoWPAN however have special design and performance requirements
Custom Protocols

- The most common solution today
- Application data typically binary encoded, application specific
- Application protocol uses a specific UDP port, application specific
- As 6LoWPAN is end-to-end IPv6 communications, not a problem
- Advantage:
  - Compact, efficient, security can be integrated, end-to-end
- Disadvantage:
  - Custom server app needed, little re-use, learning curve, interoperability
**XML/HTTP**

- De-facto for inter-server communications
- Well-known XML schema important
- All Internet servers speak HTTP/XML
- Useable for RPC, pub/sub and events
- SOAP or REST paradigm

**Advantages:**
- Well known XML schema
- Formal message sequences
- Internet-wide support

**Disadvantages:**
- Inefficient, complex

**Solution:** Embedded web-services
- Constrained RESTful Environments (CoRE) RFC6690
Implementation
Protocols Stacks

• **Contiki** – Open Source
  - Low-Power uIPv6/RPL Network and CoAP support

• **Linux** - OpenSource
  - Linux-Zigbee - ¿?
  - Since Kernel 3.8 – Support to RPL and CoAP in progress

• **Tiny OS** – Open Source
  - BLIP, the Berkeley Low-power IP stack IPv6 Ready

• **RIOT** – Open Source
  - 6LoWPAN, IPv6, RPL, TCP, and UDP . Parcial POSIX comp. Real Time

• **Arduino**
  - UIPv6 Stack – contiki ported to support Arduino Mega 2560
  - Pico IPv6 Stack – contiki ported to support Arduino PICO – without RPL

• **Nano Stack 2.0** (Sensinode)
  - Nano Stack, Nano Router, Nano Service
  - Nano Sensor

• **Jennic 6LoWPAN** (Jennic)
  - JN5139 Wireless Microcontroller, Jenie API, SNAP, JenNet
SIPIA Net
Wireless Sensor Network for Agronomical Research

SIPIA Net
Proprietary STACK (gridTiCS)

SIPIA6 Net
6IoWPAN STACK
References

- G. Montenegro, N. Kushalnagar, J. Hui, D. Culler “Transmission of IPv6 Packets over IEEE 802.15.4 Networks”, **RFC 4944** – Updated by RFC 6282 and RFC 6775
- “Neighbor Discovery Optimization for Low-power and Lossy Networks” - **RFC 6775**, November 2012.
- “Design and Application Spaces for 6LoWPANs” - **RFC 6568**, April 2012.

Gracias por su asistencia !!!

PREGUNTAS ?

Carlos Taffernaberry
UTN - Mendoza - Argentina
Carlos.taffernaberry@gridtics.frm.utn.edu.ar