Digital Investigations for IPv6-Based Wireless Sensor Networks

By

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V. Kumar, **George Oikonomou**, T. Tryfonas,
D. Page and I. Phillips

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How to Retrieve Network Data from Wireless Embedded Devices

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Tiny, Tiny, Tiny

- TI CC2530 SoC: Smaller than a dime

- 8-bit, 8051-based micro
- 8KB RAM
- 256KB Flash

- Can run TCP/IP – IPv6

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Operating Systems

- **Contiki**
  - 8-, 16-, 32-bit micros
  - 8 – 32 KB RAM
  - < 512 KB Flash
  - Dozens of supported platforms (official and unofficial)
- TinyOS
- …

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Outline

- **Motivation – Introduction**
- Extraction
- Analysis
- Correlation
- Open Issues – Further Work

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GINSENG (FP7)

- Mission-critical applications
- Operational oil refinery

- Contiki-powered nodes
- Bespoke network stack

O'Donovan et al. "The ginseng system for wireless monitoring and control: Design and deployment experiences" ACM Trans. Sen. Netw., 10, 4:1–4:40.

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Commercial Products

- Contiki-powered products at CES 14

http://contiki-os.blogspot.co.uk/2014/01/contiki-products-at-ces-2014.html

- Hacked smart objects

http://www.bbc.co.uk/news/technology-28208905

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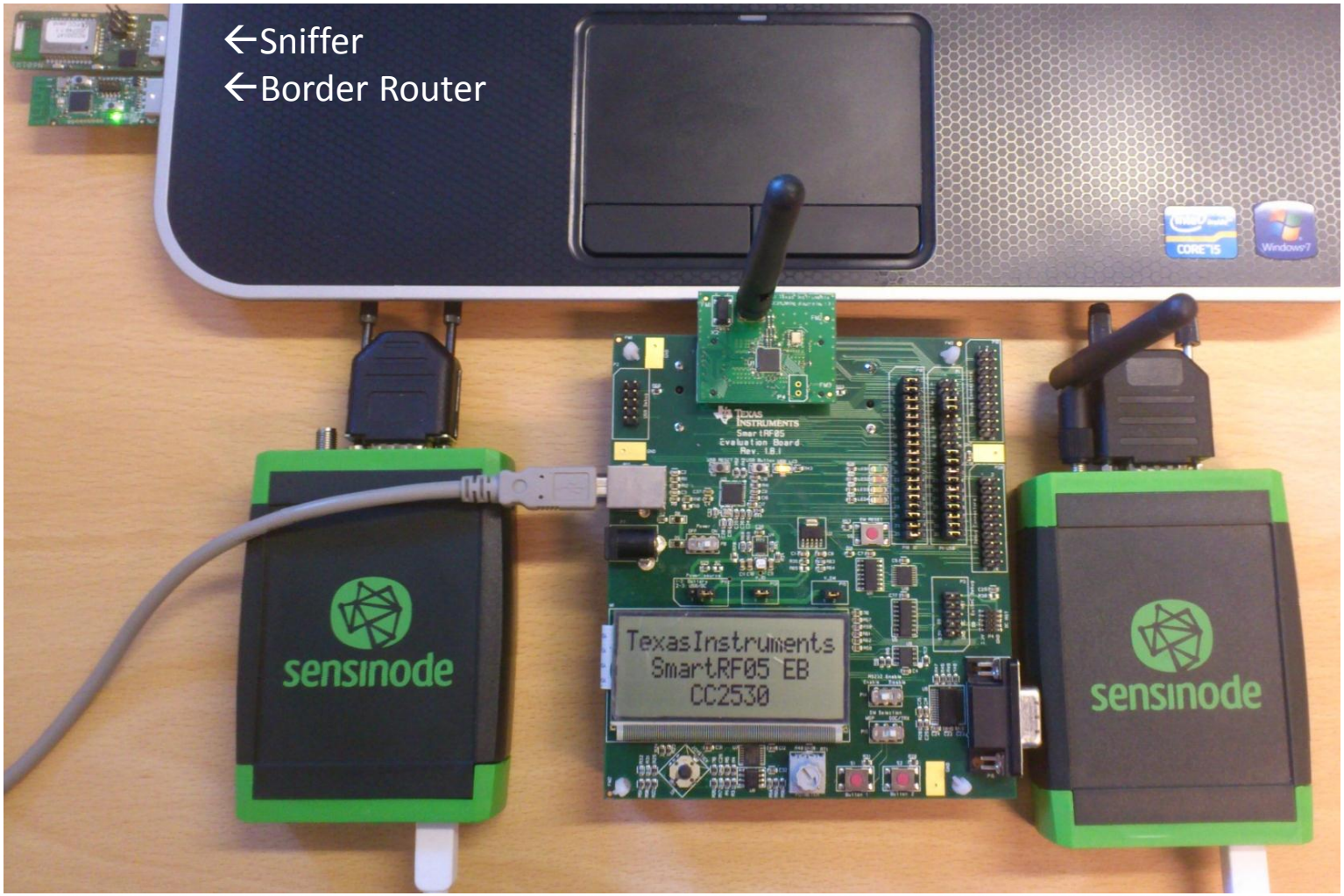
Kit



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This Work

- Recovery of networking information
  - Routing tables
  - Routing protocol metadata
  - Neighbor Discovery (ND) Cache
  - …
- Network topology reconstruction

- Focus on TI CC2530
  (+ older CC2430: big similarities = quick win)
- RAM Extraction and analysis

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Memory

- 8051 MCU – Harvard-based Architecture
  - Separate Code and Data Memory Spaces
- Physical Memory:
  - Flash
  - SRAM
  - Registers
- Memory Spaces (Distinct, Partially Overlapping)
  - CODE: Instruction memory (Flash)
  - DATA: Fast access, 256 bytes data (SRAM)
  - SFR: Registers
  - XDATA: SRAM + Flash + Registers, 64 KB, Slower Access

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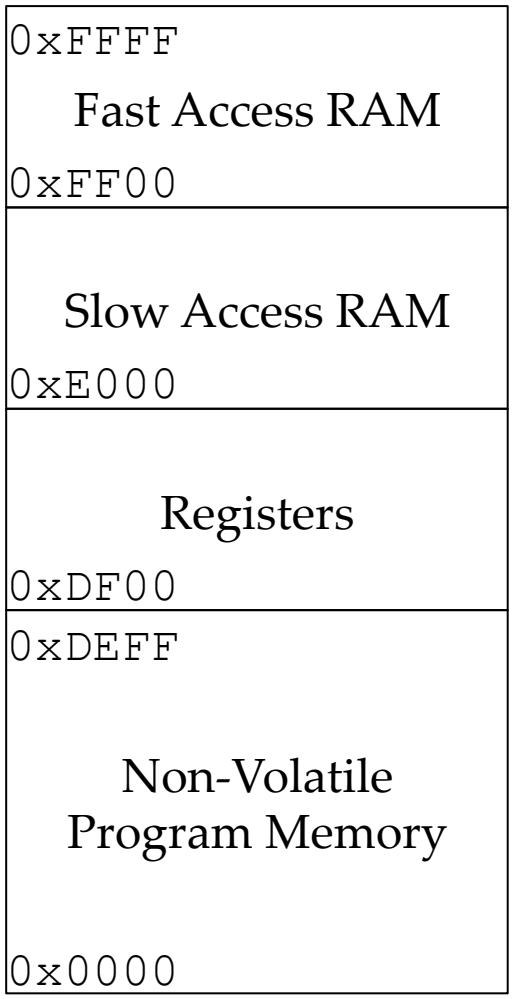
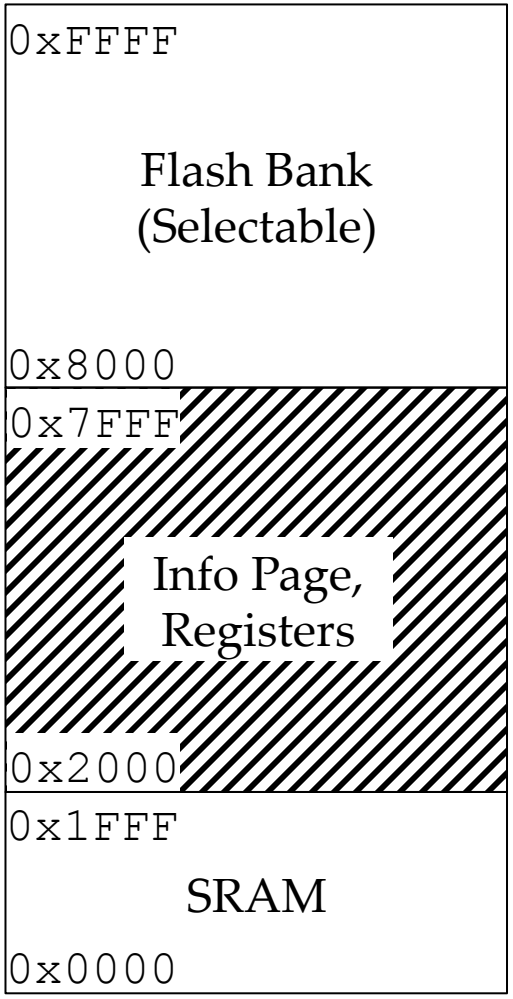
XDATA Space

CC2430





CC2530

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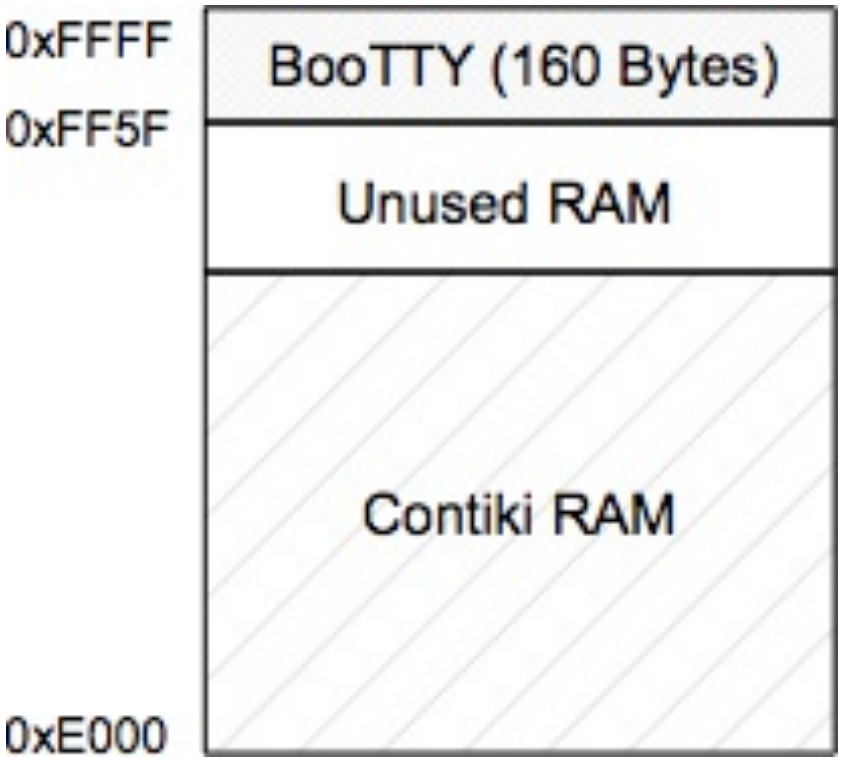
Extraction

- Over the debug interface
  - CC2530 (cc-tool)
- Over UART with a bootloader
  - CC2430
- Don’t trash the RAM!



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EUI-64 and IPv6

- An EUI-64 Identifier (8-byte MAC)

`00:15:20:00:00:02:20:EB`

- A Link-Local IPv6 Address (LL IPv6)

`FE80:0000:0000:0000:0215:2000:0002:20EB`

`FE80::0215:2000:0002:20EB`

- A Routable IPv6 Address (Unique-Local)

`FD4D:4267:5F8C:0000:0215:2000:0002:20EB`

`FD4D:4267:5F8C::0215:2000:0002:20EB`

EUI-64 and IPv6: On RAM

EUI		00 15 20 00 00 02 20 EB
LL IPv6	[8 bytes]	02 15 20 00 00 02 20 EB
UL IPv6	[8 bytes]	02 15 20 00 00 02 20 EB

Observations:

1. Interface ID derived from EUI-64 with 1 bit inverted (the U/L bit)
2. One link-local and one routable v6 same If ID

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Analysis

- Find all 16-byte block occurrences of:
  `FE 80 00 00 00 00 00 00 [ If ID ]`
  Gives us a list of 8-byte `[ If ID ]`s
- For each `If ID`, find all 16-byte blocks:
  `[ not FE80:: ] [ If ID ]`
  first 8-bytes of each match are a candidate network prefix `(PREFIX)`
- For each `PREFIX`, search for 16-byte block occurrences of:
  `[ PREFIX ] [ any 8 bytes ]`
  more candidate IPv6 addresses

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Analysis

3 full passes across entire RAM, very quick

We now have:

- List of candidate IPv6 addresses on RAM
- For each of those, invert the U/L bit in `[ If ID ]`
- List of candidate EUI-64s present on RAM

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Data Types

Listing 1: An entry in Contiki's ND Cache

```
typedef struct uip_ds6_nbr {
  uint8_t isused;
  uip_ipaddr_t ipaddr;
  uip_lladdr_t lladdr;
  /* Meta Data */
} uip_ds6_nbr_t;

uip_ds6_nbr_t uip_ds6_nbr_cache[SIZE];
```

Listing 2: An entry in Contiki's Default Routes Table

```
typedef struct uip_ds6_defrt {
  struct uip_ds6_defrt *next;
  uip_ipaddr_t ipaddr;
  struct stimer lifetime;
  uint8_t isinfinite;
} uip_ds6_defrt_t;
```

Listing 3: Extract of the RPL parent data structure

```
struct rpl_parent {
  struct rpl_parent *next;
  struct rpl_dag *dag;
  rpl_metric_container_t mc;
  uip_ipaddr_t addr;
  rpl_rank_t rank;
  /* more fields */
};
```

Listing 4: An entry in Contiki's Routing Table

```
typedef struct uip_ds6_route {
  struct uip_ds6_route *next;
  uip_ipaddr_t ipaddr;
  uip_ipaddr_t nexthop;
  /* more fields */
} uip_ds6_route_t;
```

- Knowledge of Data-Types
- No knowledge of data structure memory address

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Example: ND Cache

Statically pre-allocated array of entries:

- Each one is a `struct uip_ds6_nbr`
- Fixed length
- Strict pattern:

```
01 [ LL IPv6 ] [ EUI-64 ] [ meta ]
```

We don’t need to parse, we already have a list of all EUI-64s + their locations

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Smooth Sailing

- Node's own IPv6 addresses and EUI-64
- Routing table
- Default route (stored separately)
- RPL:
  - Parents
  - Instance table
  - DODAG info
- Interface info, multicast addresses

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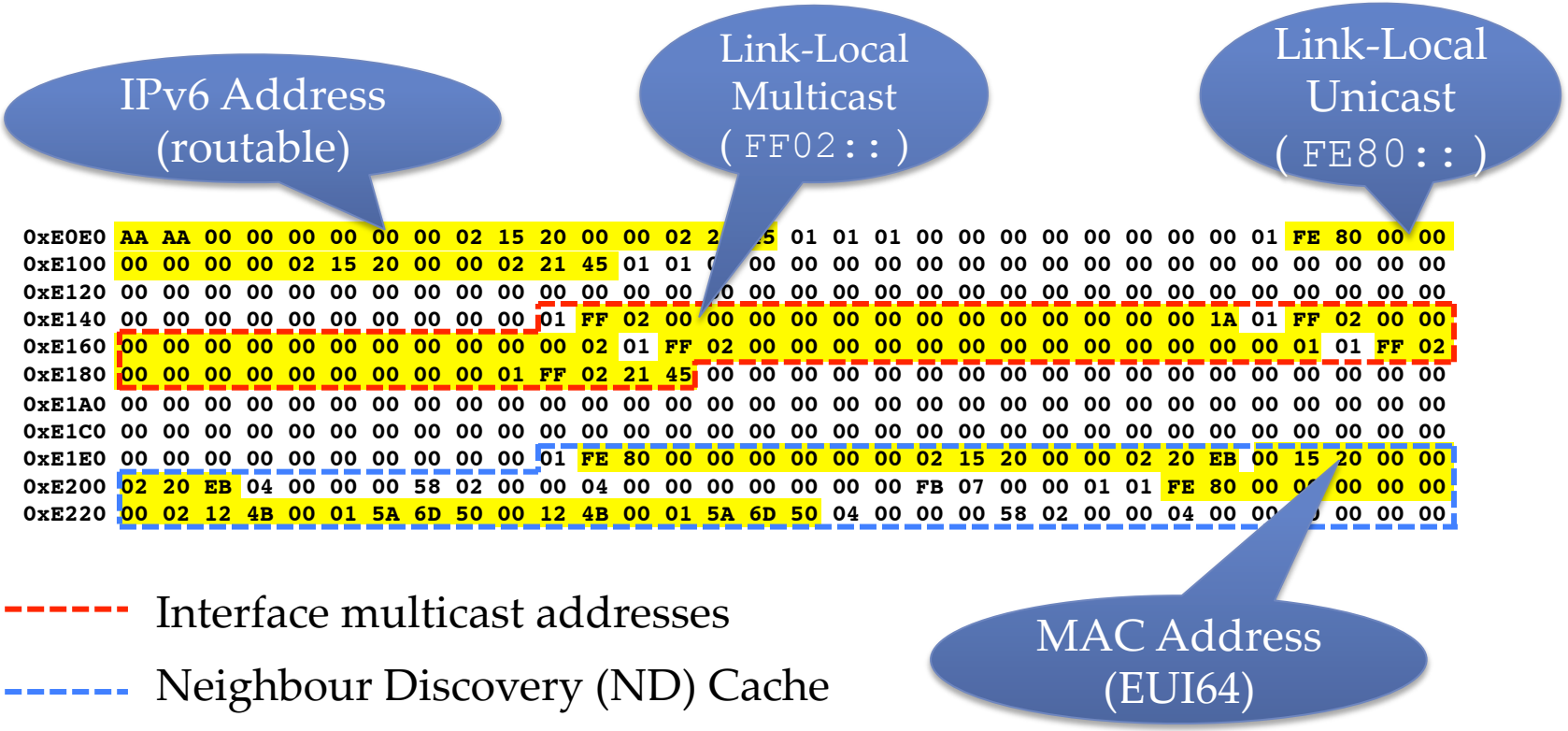
RAM Analysis

RAM Contents of an 8051-based Micro Powered by a Contiki Firmware



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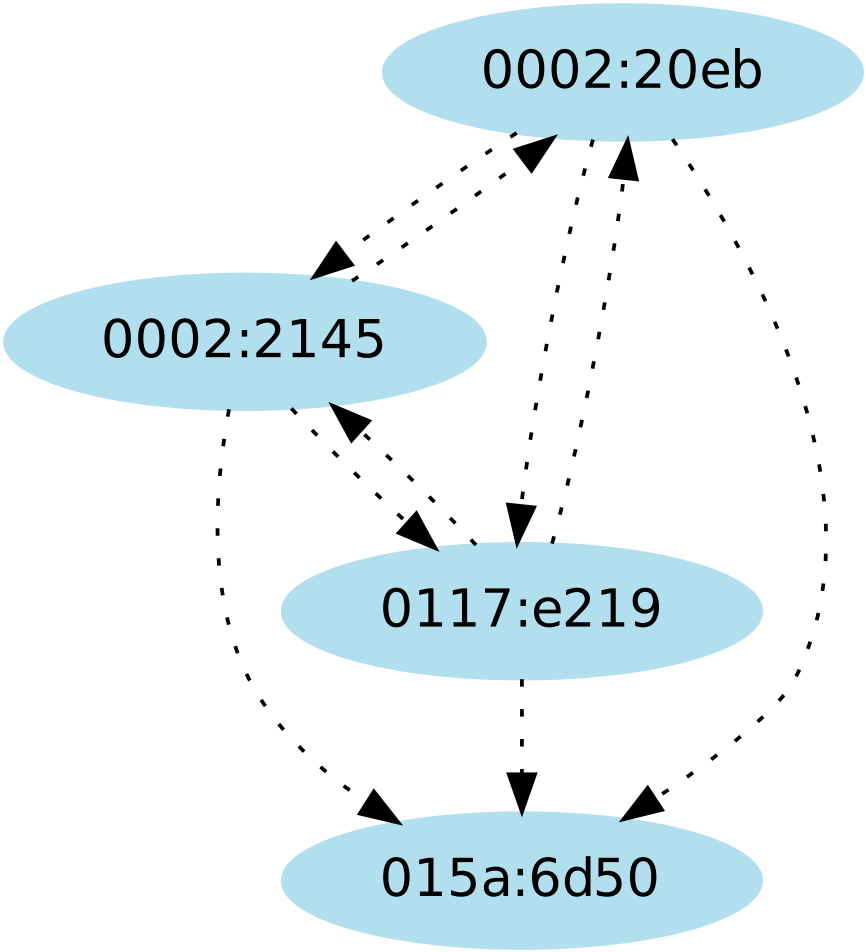
Link Layer



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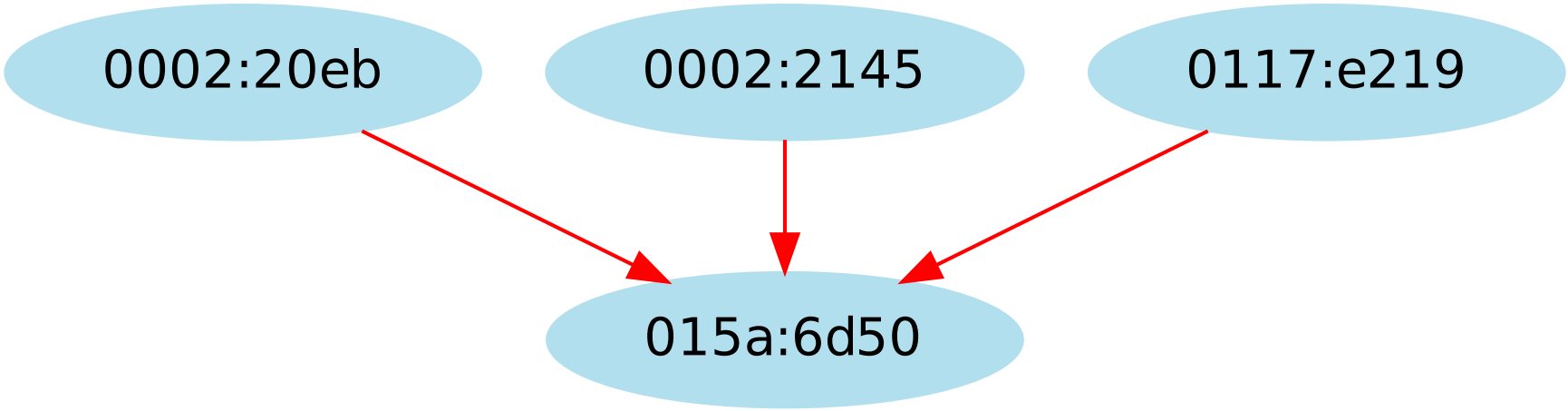
Network Layer



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Open Issues

- Data loss after device resets:
  - RAM retention characteristics
  - Data structure initialization at startup
- Locked debug bits

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Future Work

- More OS versions
- More architectures (Arm CM3, msp430)
- Large-Scale Networks
- Forensic Readiness

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ForToo

- Digital forensics for emerging technologies
- Smartphones
- Social networks
- Internet of Things

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Thank You!

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Data Loss

Device and Use-Case	Device not Reset	Device Soft-Reset	Device Power-Cycled
Sensinode N740			
Bootloader Pre-Installed	Success		Partial
Bootloader Installed by Investigator	Partial	Partial	Failure
SmartRF05EB + CC2530EM	Success	Data Overwritten	Data Overwritten

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RERUM

Security, Privacy, Reliability for the IoT

- FP7 STREP: Grant nº 609094
- Start: 1st September 2013
  Duration: 36 months
- Total Cost: €5,196,176.00
- Consortium:
  - 12 partners from 6 countries
  - 2 Local Authorities
- https://ict-rerum.eu

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement nº609094.

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