Security of MICA*-based / ZigBee Wireless Sensor Networks

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Our approach

What we did

1. Development of systems for monitoring large civil structures
2. Analysis of off-the-shelf products
3. Interviewing owners and/or operators of the structures
4. Implementing attacks

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The kit

- MICAz motes – purchased as part of a Xbow kit
- Stargate – embedded Linux box with a MICAz connector
- USB programmers / receivers for MICAz
- Hardware debugger – Atmel JTAG ICE
- VMware and serveral Linux/Win boxes

Most results applicable to Iris, Tmote, Intel Mote and Intel Mote 2 devices.

They also use TinyOS software or its commercial versions.

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Three-tier architecture

- Your standard three-tier network topology
  - back-end system with database (off-site) Comms: ADSL where possible, GPRS
  - middle: gateway (on-site) Comms: IEEE 802.15.4 / RS-232
  - bottom: sensor nodes (multi-hop ad-hoc network)
- Actual hardware components
  - Crossbow backend system (with PostgreSQL database)
  - Stargate (embedded Linux box as a gateway)
  - Crossbow MICAz (802.15.4 motes)
  - TinyOS 1.1 / XMesh (OS for MICAz motes)

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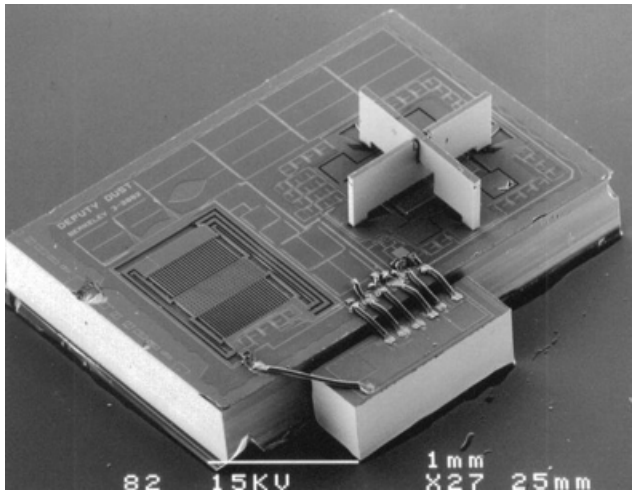
The myth of smart dust . . . and security



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The myth of smart dust . . . and security

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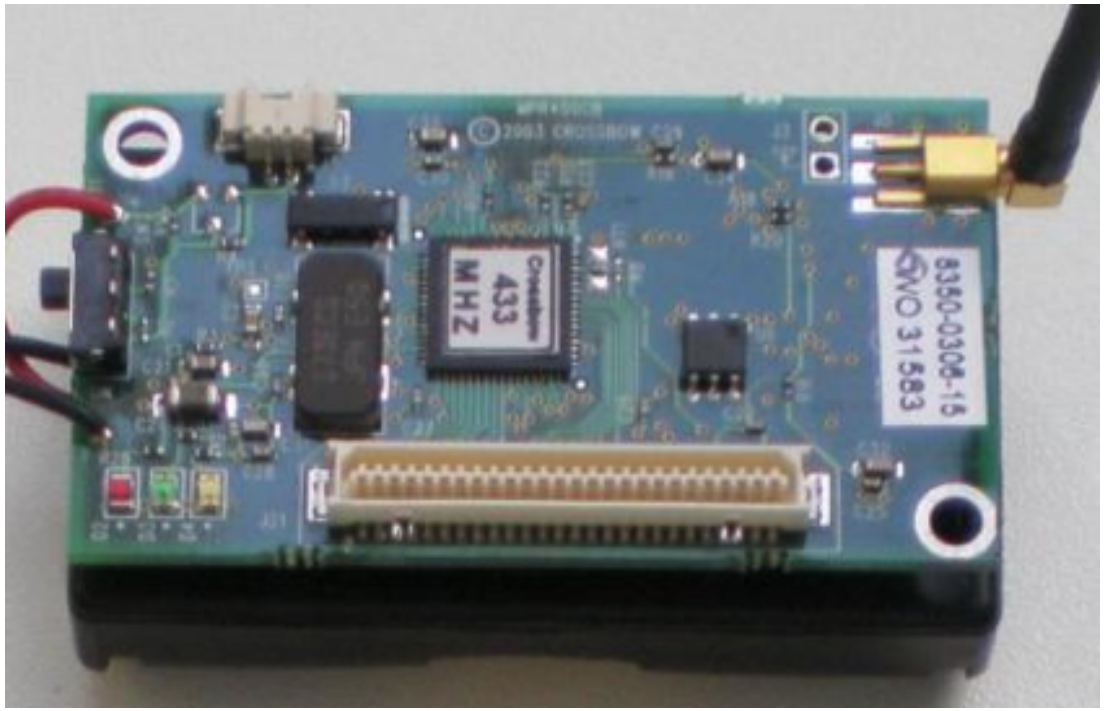

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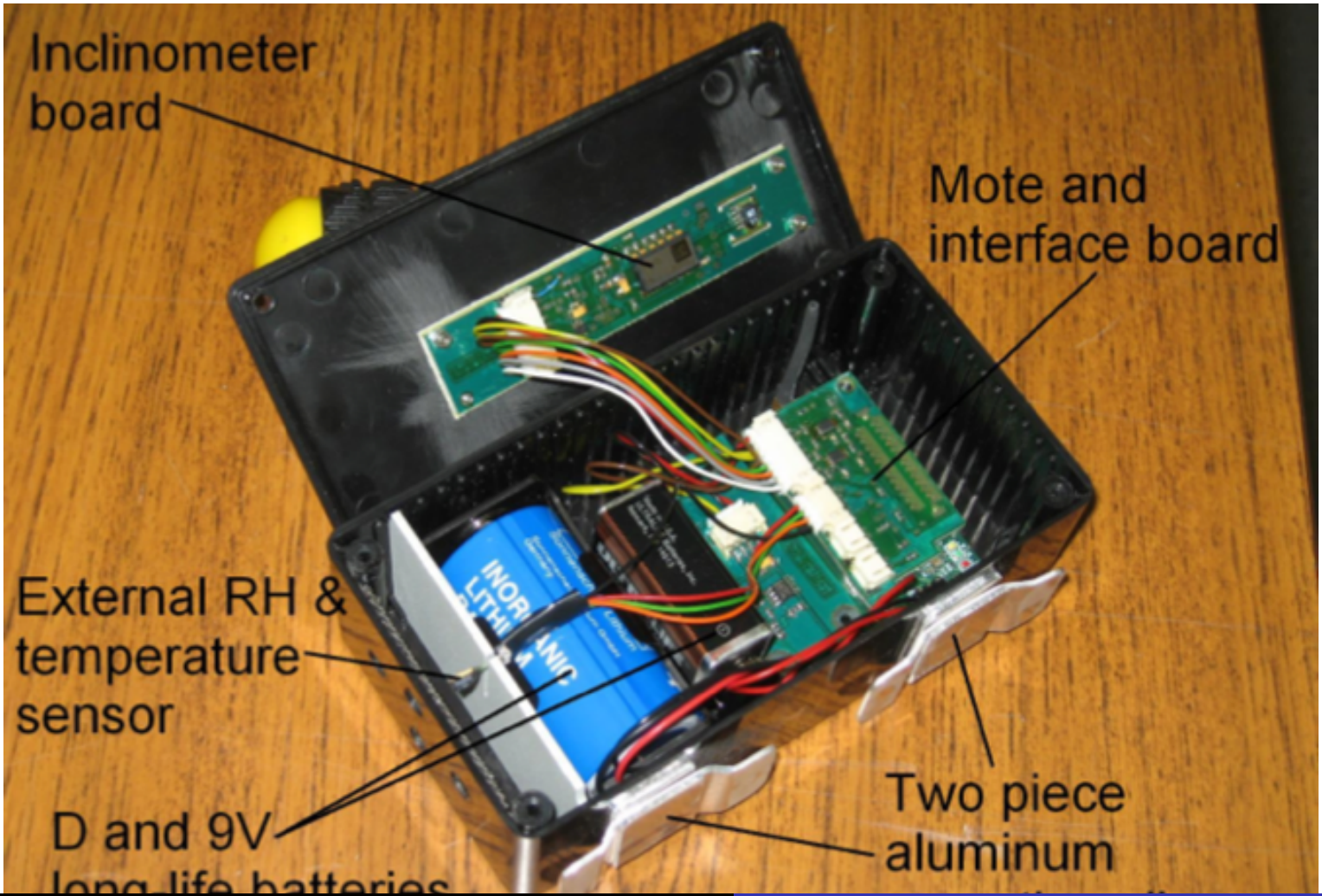

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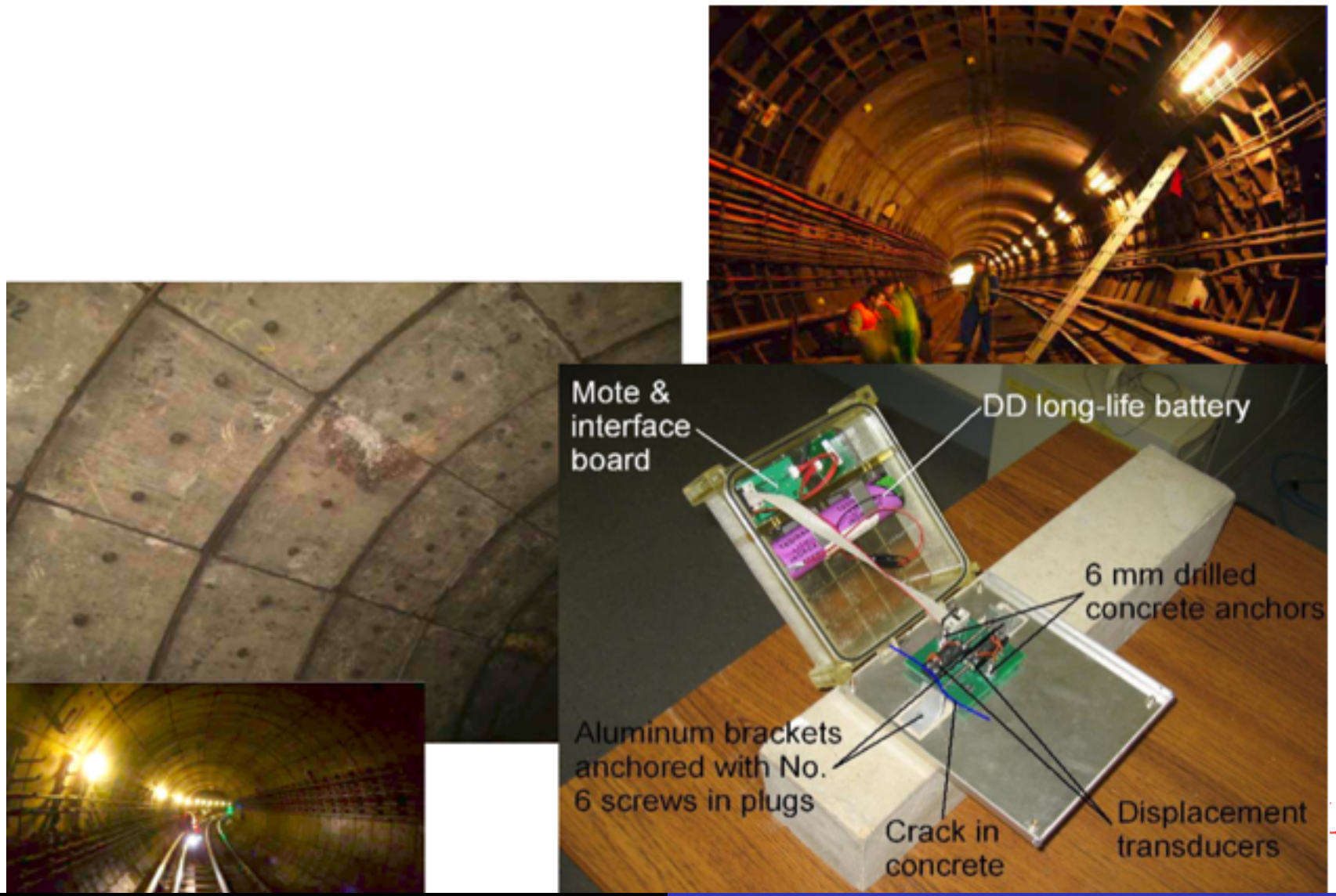
Mote &
interface
board
DD long-life battery
6 mm drilled
concrete anchors
Aluminum brackets
anchored with No.
6 screws in plugs
Crack in
concrete
Displacement
transducers

Security properties – by civil structures' operators

What the operators want

- Confidentiality
  - Not really an issue (bridge, underground)
  - Do not rule encryption out but use it by default
- Availability
  - Becomes critical if used be quick response mechanisms
  - Reliability is however a basic requirement

What stroke us was that managers we talked to were not able to predict future applications.
However, overloading existing infrastructures was common (answers to direct questions).

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Security properties

- Short-term integrity
  - False negatives – hard to exploit if only few **true** positives!
  - False positives – more disruptive; but viewed with suspicion
- Medium-term integrity
  - Month-scale analysis helps budgeting for maintenance costs
  - Continuous monitoring gives quantitative answers
- Long-term integrity (up to 100+ years)
  - Scale of decades: allows previously impossible research
  - The most valuable data
  - System to be designed for portability and continuous upgrades

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Attackers / Risks

This is for now

(imagine a future when you can use ZigBee networks to . . .)

- Terorists?
  - No, they will target bridges and tunnels directly
- Competitors, resourceful attackers?
  - Not likely
- Curious hackers
  - Possibly, to play a bit with the technology

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Attackers / Risks

Risk of attacks – not amplified by WSN.

But may be differnet for water pipes.

It is quite easy to get through a pad lock.

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Classes of attacks

Three basic attack classes

- Remote attacks – from the Internet
- Vicinity attacks – wireless, within communication range
- Physical attacks – physical access to targeted devices

Physical attacks are difficult to do (Becher, Benenson, and Dorseif in 2006)

What about just connecting to a mote's connector??

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Code analysis – why?

XMesh – commercial variant of TinyOS

Disassemble XMesh code (15k ASM lines)
and use variable names from TinyOS

```
if (pTable-> flags&NBRFLAG_VALID){
  if (pTable->flag&NBRFLAG_VALID) && (pTable->parent != TOS_
      &&(pTable->parent!=-1) && (pTable->cost !=-1)
      && (pTable->childLiveliness==0))
    computeCost(pTable->cost, pTable->sendEst, pTable->rece
                ulNbrLinkCost, ulNbrTotalCost);
    if (pTable==gpCurrentParent){
      pOldParent=pTable;
      oldParentCost=ulNbrTotalCost;
      oldParentLinkCost=ulNbrLinkCost;
    } else {
      if (ulNbrTotalCost < ulMinTotalCost){
        ulMinTotalCost = ulNbrTotalCost;
        pNewParent = pTable;
```

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Routing metrics

- Routing is based on
  1. link cost – ratio of successfully received / sent messages
  2. route cost – sum of link costs to a gateway
- The basis of all computations are message counters
  1. XMesh does not include counters into data messages

Function UpdateNbrCounters

```
sDelta = seqNo - pNbr->seqNo - 1
if (seqNo!=1)  {
    sDelta--  //the only change from TinyOS
}
if (sDelta >= 0) {
    pNbr->missed+=sDelta
    pNbr->received++
} else {  // sDelta was < 0
    if (sDelta < -20) {
       // forget and reinitialise the record
   } else {
        return TRUE
   }

pNbr->lastSeqNo = seqNo
```

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XComand vulnerability

XCommand feature

- Xbow's extension of TinyOS
- Direct commands from a gateway to all / selected motes
- No routing but broadcast instead

How to stop rebroadcasting? Messages have msgIDs

- Each mote keeps internal counter (e.g., moteCntr)
- Mote does not process if $moteCntr \geq msgID$

The problem is *moteCntr* is not the last seen *msgID* but the number of processed XCommand messages

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Attacks

Hardware limits

Memory is limited $\Rightarrow$ all data structures are size-limited!

- Counters
- Tables
- Crypto information

Not always necessary

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Jamming

Jamming

Power used by attacker power wasted by victim

Or can it be used for “smart” attacks?

Jamming

Jamming

Power used by attacker $>$ power wasted by victim

Or can it be used for “smart” attacks?

Jamming

Jamming

Power used by attacker = power wasted by victim

Or can it be used for “smart” attacks?

Jamming

Jamming

Power used by attacker $<$ power wasted by victim

Or can it be used for “smart” attacks?

Jamming

Jamming

Power used by attacker $<<$ power wasted by victim

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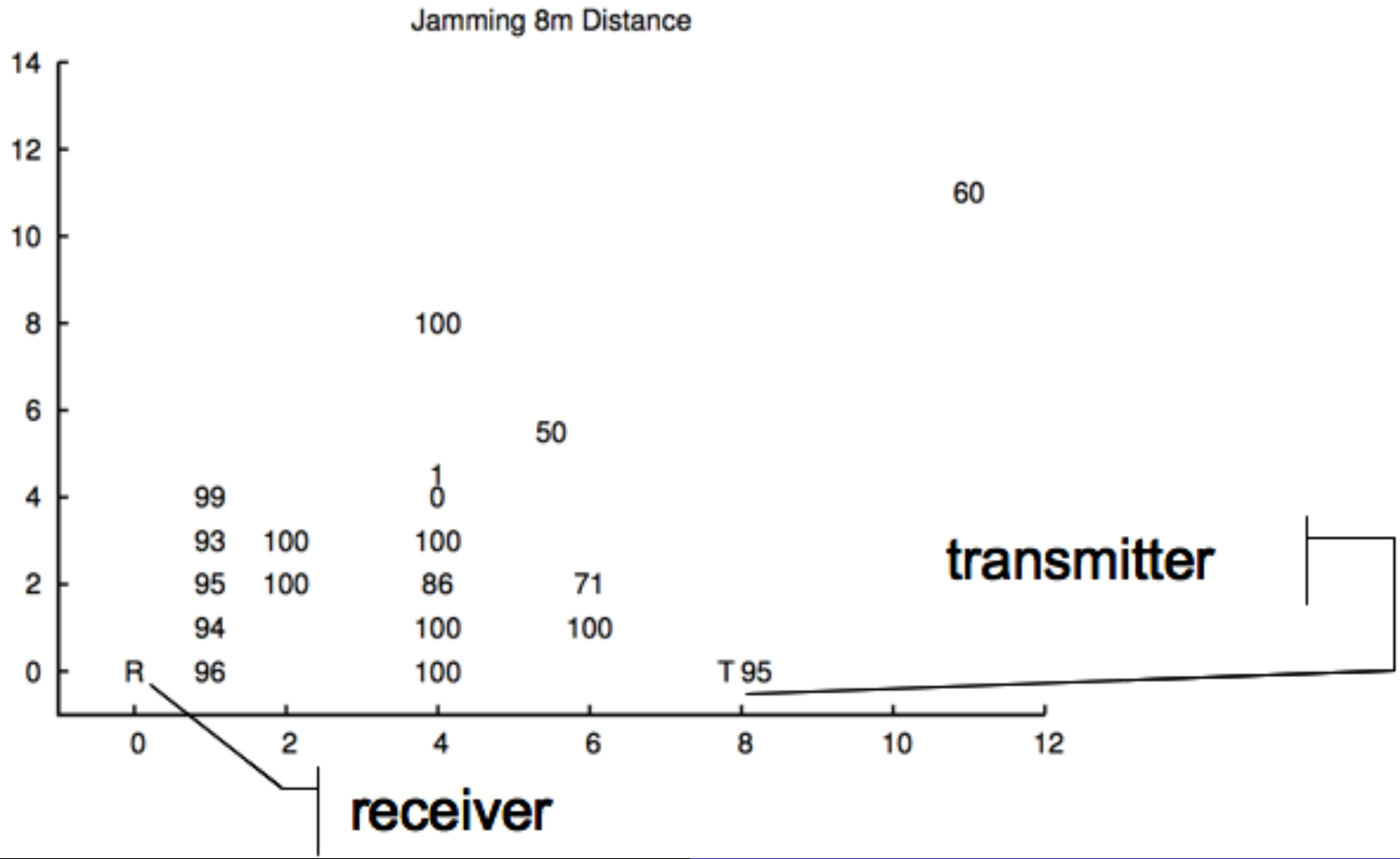
Jamming


Jamming 8m Distance
14
12
10
8
6
4
2
0
0
2
4
6
8
10
12
R
T
60
100
50
1
0
99
93
95
94
96
100
100
100
86
100
100
71
100
95
transmitter
receiver

Selective jamming

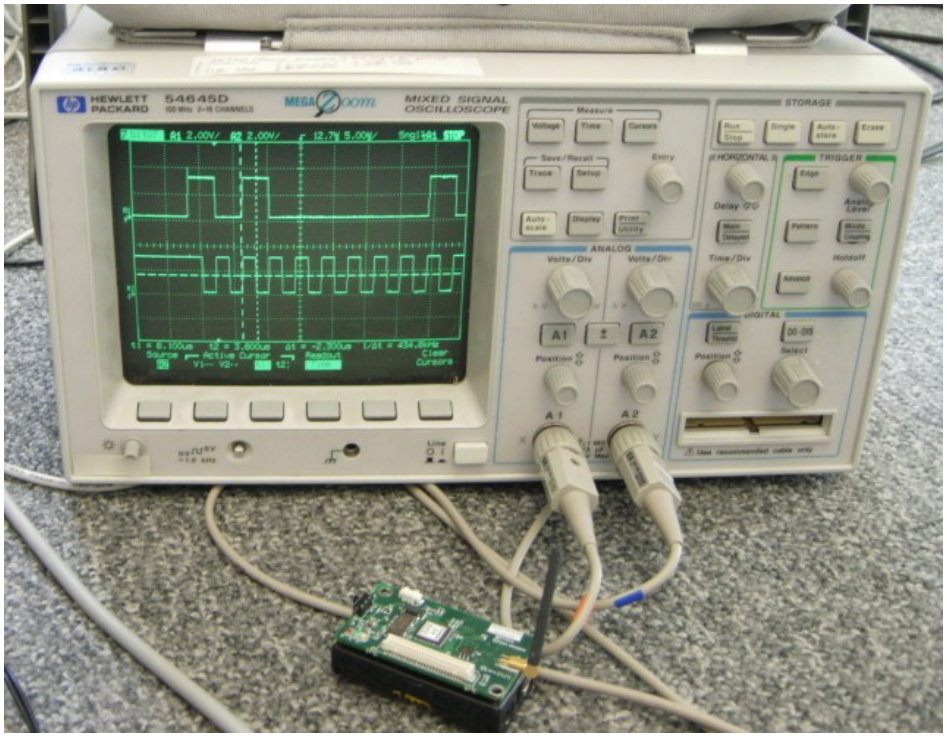
- Jamming always possible – no news
- More interesting – selective jamming
  - Jam packets from mote *X*
  - Jam packets for mote *Y*
  - Jam packets of type *Z*
  - Jam packets with content *C*
- Simple but effective implementation
  - compile criterion into attacking mote's code
  - Deploy the mote and let it listen
  - If a message meets the criterion, jam

Low cost selective jamming

Can we use just one mote to listen and jam selectively?
Problem – IEEE 802.15.4 radio chips work over buffers.

Low cost selective jamming

Solution – debug mode



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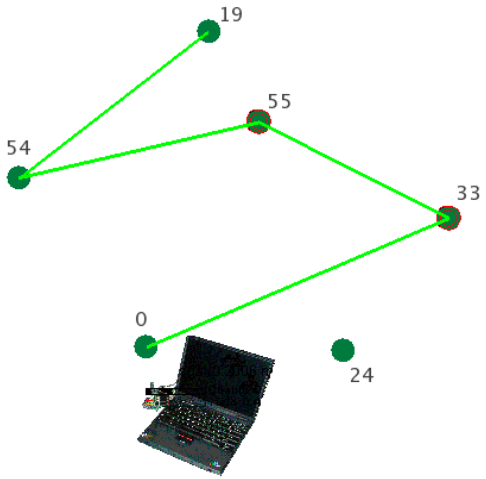
Low cost selective jamming

The final code well below 100 lines of NesC (C macro language)

Jamming – transmitting fixed bytes on the same channel.



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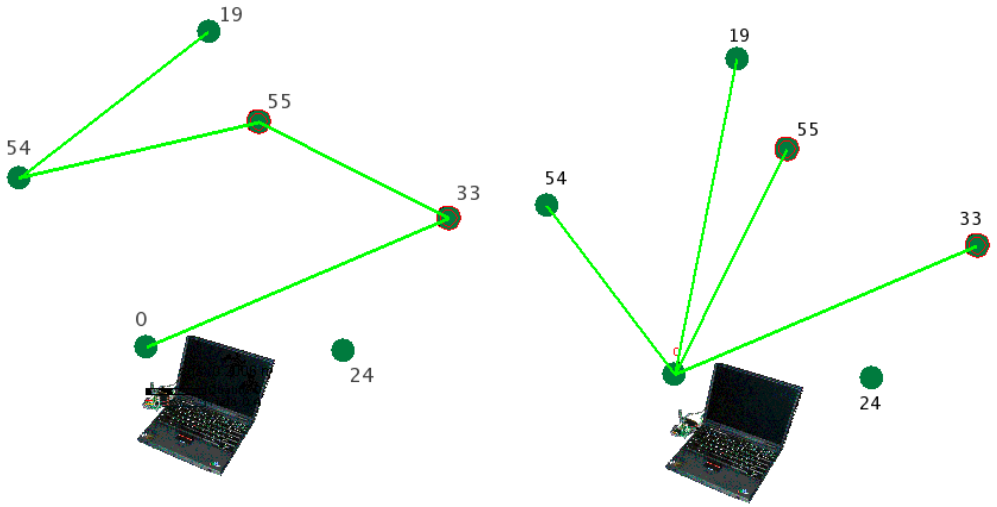

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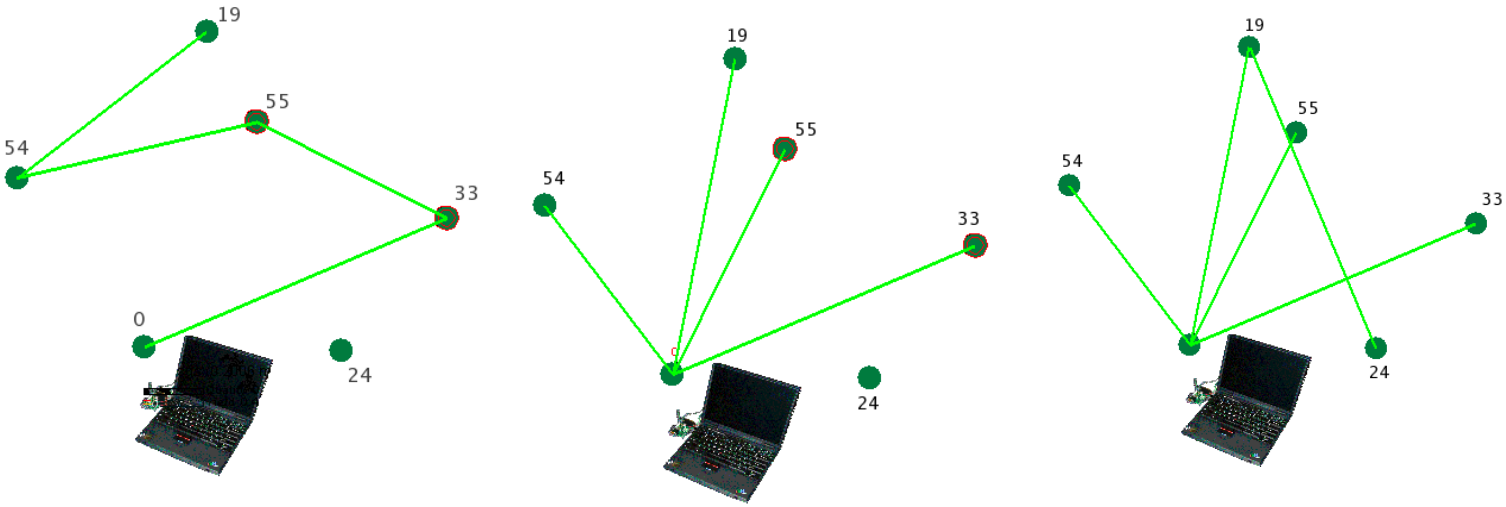

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Protection?

Routing table manipulation

- XMesh nodes broadcast neighbour lists with link quality info
- Nodes update own routing tables by according to messages (no crypto)
- Scapy extension to manipulate/inject messages
- One cen indirectly rewrite routing table of victim

"Sleep deprivation attack"

1. Create a routing loop between two victims
2. Watch them zip messages back and forth (if you want)
3. Let them drain batteries (duty cycle $< 1\ \% \rightarrow >> 10\ \%$)

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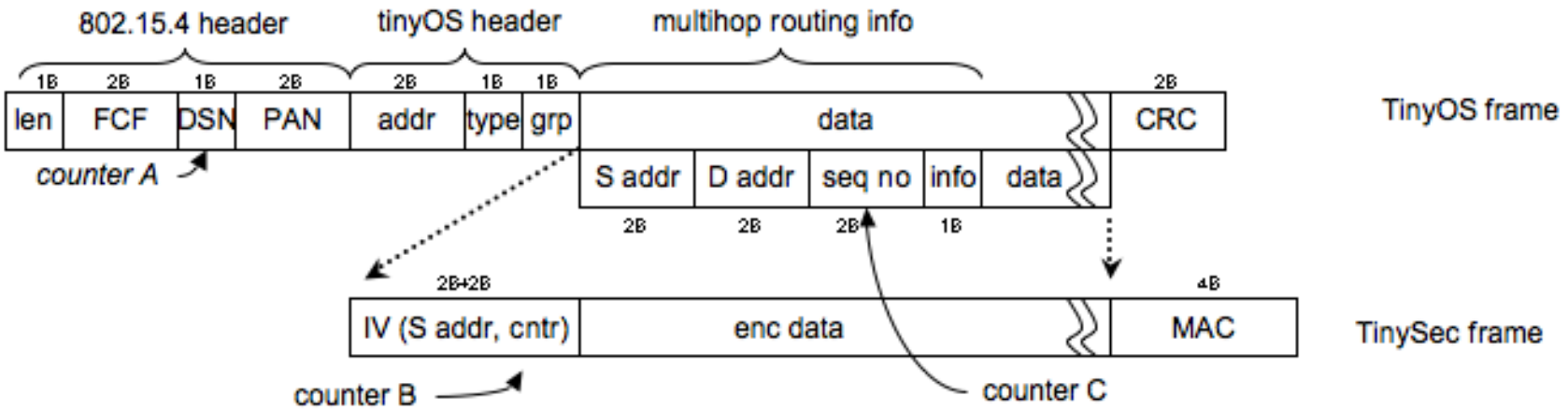
Frame formats



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Msg replays - counter overflow

Messages rejected if the msg counter < expected value
BUT
If the msg counter > expected value, it will be accepted
(also if msg counter = NOUGHT)

Counter size – 16 bits $\Rightarrow$ let's cause overflow

- Inject fake message the victim will forward
  (data msgs no counter)
- Create a routing loop (quickly eating up counter values)
- Jam ACK frames – the victim will retransmit

Combine any of the three.

Or, as the routing table size is 16,
just add as many new neighbours.

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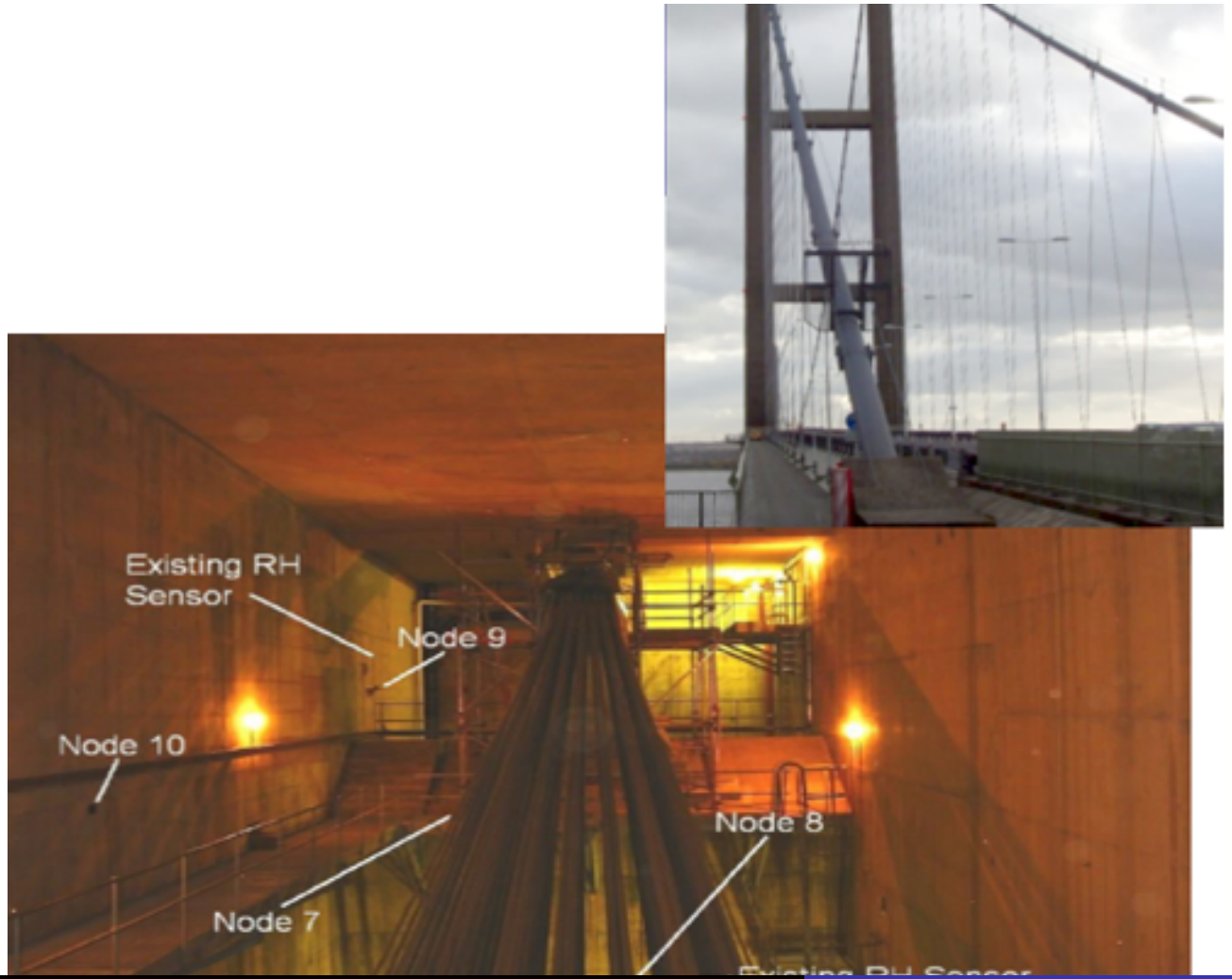
Traffic analysis

The exterior



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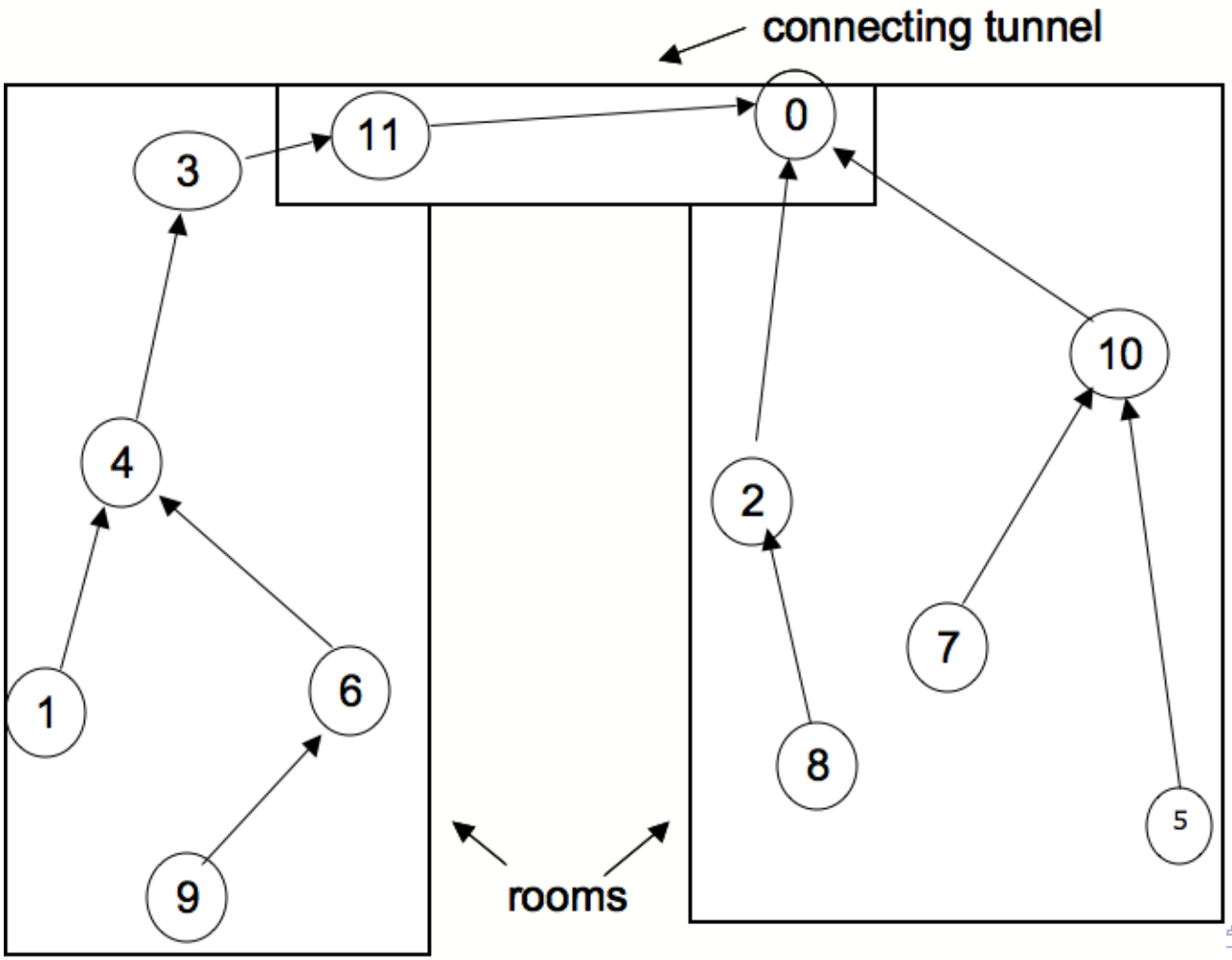
Network topology



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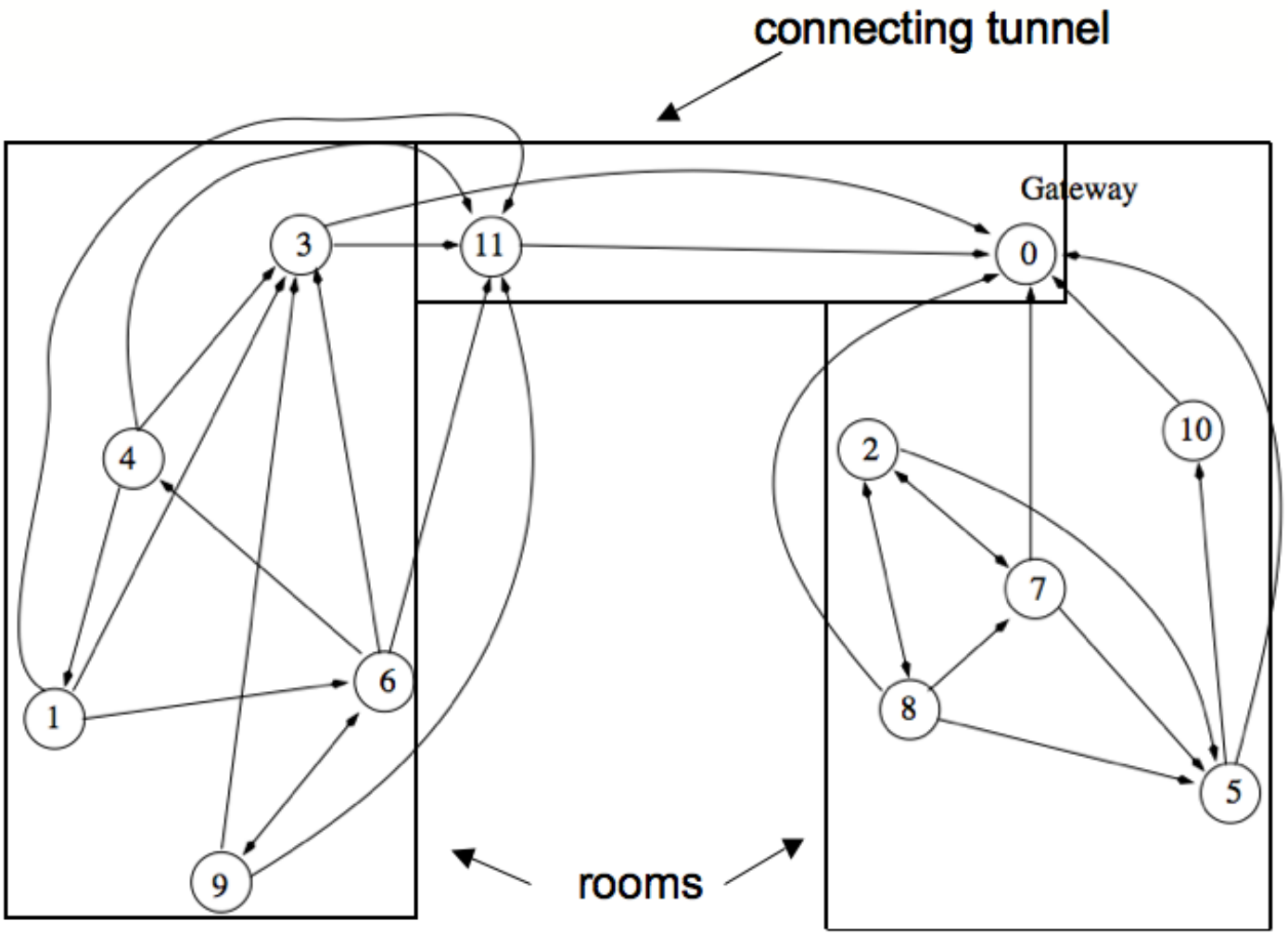
Network topology over 24 hours



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What can one play with

Traffic analysis allows

- Topology – never encrypted
- Routes to gateway – partially encrypted
- Data – encrypted

Cryptography

What is out there?

TinySec – crypto library allowing encryption and MACing

Only MICA2 motes – not ZigBee motes

We had to port TinySec for MICAz motes first!
RF chip $\Leftrightarrow$ [Tx/Rx $\leftrightarrow$ TinySec $\leftrightarrow$ Tx/Rx $\leftrightarrow$ Processing]
$\leftrightarrow$ - 1 byte for MICA2 (868/916 MHz RF)
$\leftrightarrow$ - 1 frame for MICAz (2.4GHz / 802.15.4 RF)

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Types of cryptographic problems

- Correctness of implementation
- Computational limitations
- Usage limits / errors

Implementation errors

Processing of eight-bytes block: CBC-MAC

```
for (i = 0; i < msgLen; i++) {
   // unroll
   partial[pos++] ^= msg[i];
   if (pos == 7) {
      if (!call BlockCipher.encrypt
                (&context->cc, partial, partial)) {
         return FAIL;
      }
      pos = 0;
   }
```

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Hardware limits for crypto

Personally, I don't think there are any.

TinyOS

- MAC length 4 bytes
- Power efficient symmetric ciphers
- Public key cryptography?

Power consumption of computations v communication

- MAC overhead, synchronisation, . . .

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Cryptographic boundary

TinySec is excellent because it's transparent for gateway

Different treatment of wireless and wired interfaces

A few words from Xbow

A few points from communication with Xbow

- Our customers are universities (i.e., they only want to play)
- We agree that security issues highlighted must be solved
- We are not interested in security until we have customers

Project webpage:

http://www.cl.cam.ac.uk/research/security/sensornets/

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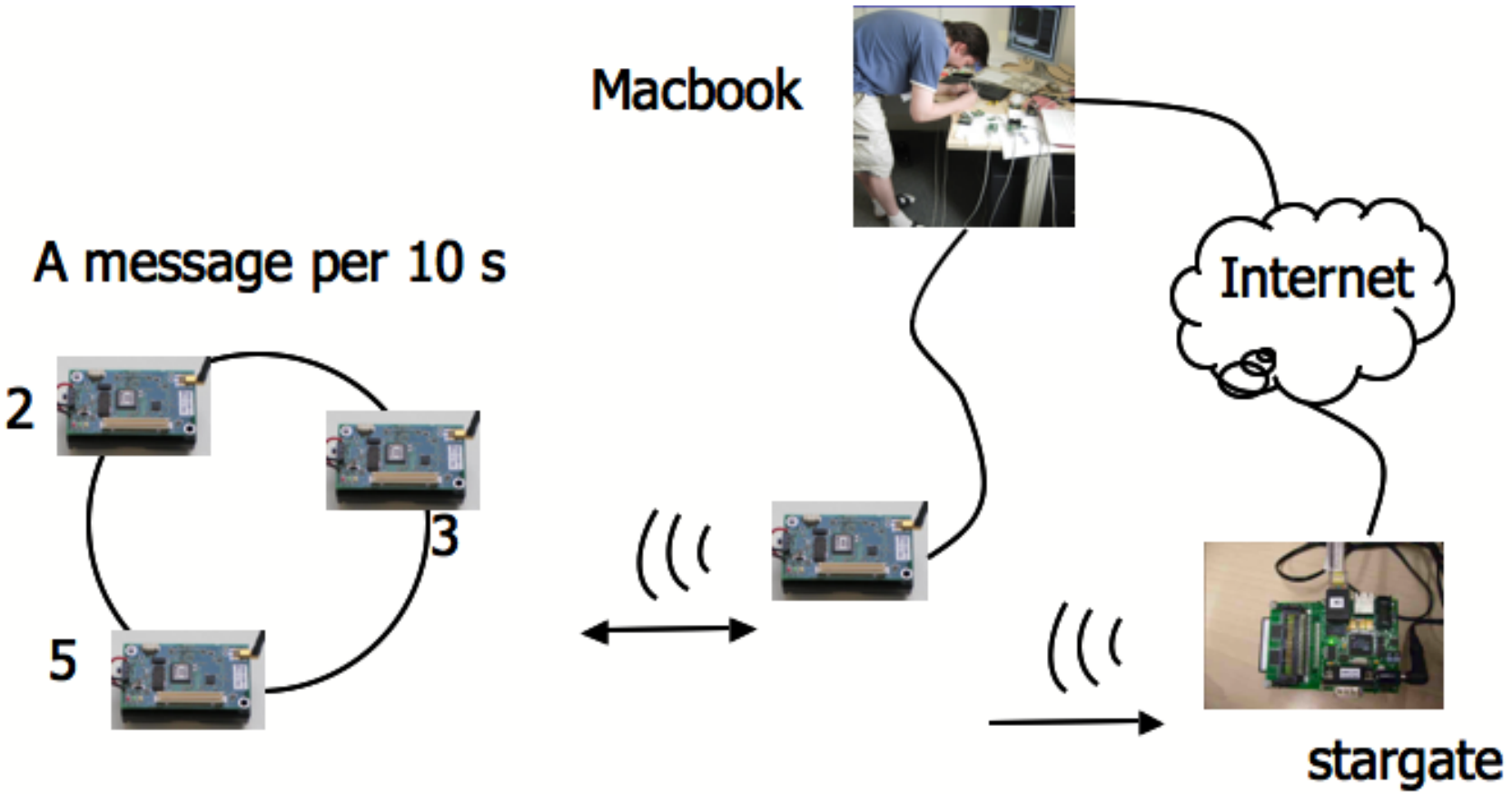

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