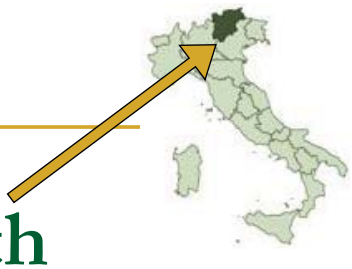
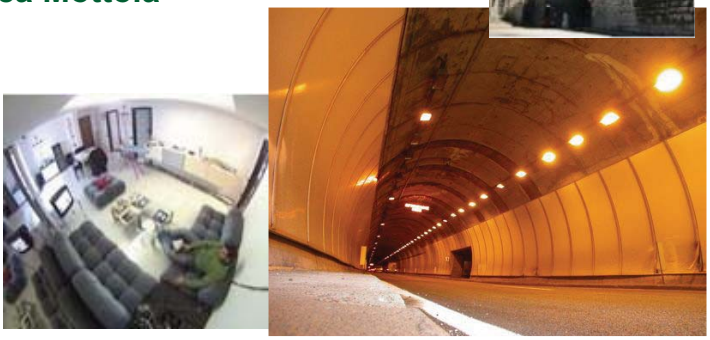


Structural monitoring with WSNs Trento, Italy

Amy L. Murphy (`es.fbk.eu/people/murphy`)
Bruno Kessler Foundation – IRST, Italy

joint work with:
Gian Pietro Picco (University of Trento),
Matteo Ceriotti, Stefan Guna, Luca Mottola
… and many others …



Heritage Buildings

The Case of Torre Aquila

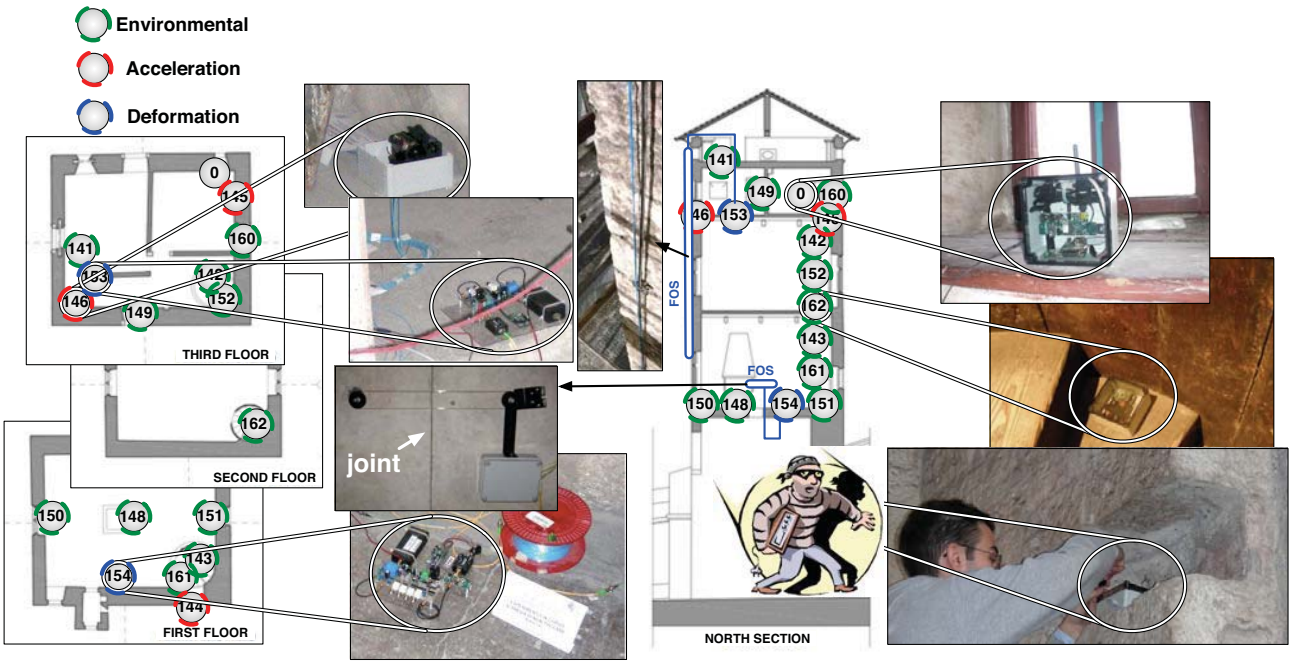
- 31-meter medieval tower
  - Contains the “Ciclo dei 12 mesi”
- Structural concerns due to traffic patterns
  - Deformation, response
- Traditional data loggers
  - cumbersome, invasive, and expensive
- WSN offer viable alternative
  - Wireless monitoring
  - Minimum invasiveness
  - High sensing granularity
  - Flexibility and ease of relocation

M. Ceriotti, L. Mottola, G.P. Picco, A.L. Murphy, S. Guna, M. Corra', M. Pozzi, D. Zonta, and P. Zanon. Monitoring Heritage Buildings with Wireless Sensor Networks: The Torre Aquila Deployment. In Proceedings of the 8th ACM/IEEE International Conference on Information Processing in Sensor Networks, San Francisco (CA, USA), April 13-16, 2009. ***Best Paper Award***

Peculiarities of Our Study

- Some experiences in WSNs for civil engineering
- Torre Aquila poses peculiar challenges
- ***Heterogeneity***
  - different types of sensors working with different modalities
    - data rates from minutes up to several hundred Hz
- ***Temporal span***
  - monitoring must span months or even years
    - e.g., to study seasonal changes
- ***Online tasking***
  - change the system behavior remotely depending on requirements
    - e.g., when visitors are in the tower

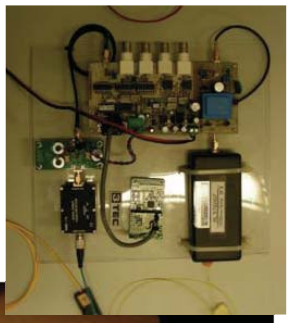
WSN Deployment in Torre Aquila

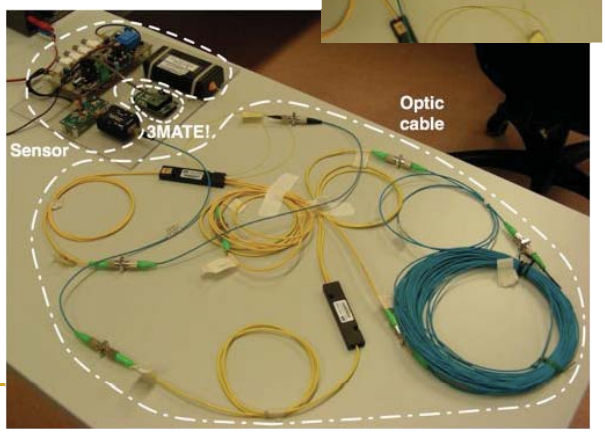


Hardware

Base Node, Environmental and Deformation Sensors

- WSN node: TRETEC 3MATE!
- 3MATE! environmental board
  - analog temperature (± .5°C, -40° to 125°C)
  - light (10lx to 1000lx)
- Deformation measured with fiber optic sensors
  - read-out unit, laser pulser, optical receiver
  - interfaced to 3MATE! via serial protocol

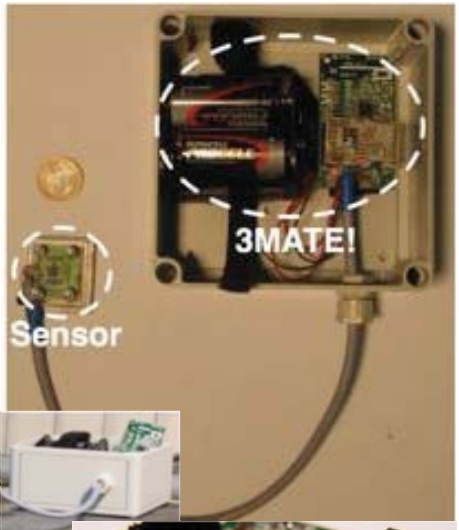


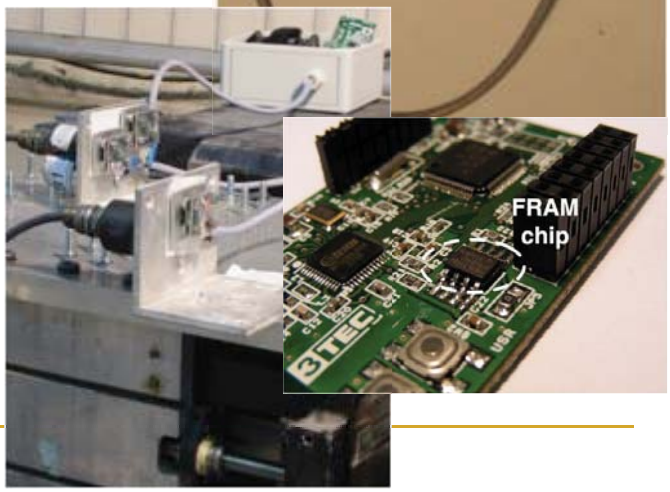


Hardware

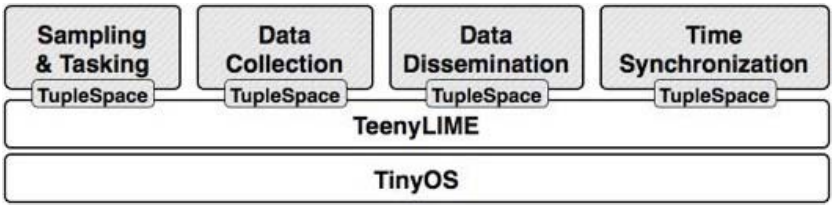
Acceleration Nodes

- Tri-axial analog MEMS inertial sensor
  - ± 2*g*, 1.5 KHz bandwidth, ±1m*g* over 100 Hz bandwidth
  - calibration with shake table and piezoeletric sensors
- FRAM chip
  - faster read/write enables accel sensing up to 1KHz rate
  - energy efficient
  - much higher number of R/W operations





Software
Architecture



- The ***TeenyLime*** middleware provides (1-hop) neighboring nodes with a shared memory space
  - components read/write ***tuples***
- Language constructs dedicated to WSN processing
  - ***reactions*** allow asynchronous notifications when data of interest appear in the tuple space
- Enables developing ***applications*** and ***system-level*** functionalities (e.g., routing)
- A cost worth paying…

P. Costa, L. Mottola, A. Murphy, and G.P. Picco.
"Programming Wireless Sensor Networks with the TeenyLIME Middleware."
In Proc. of the Int. ACM/USENIX Middleware Conf., 2007.

Software
TeenyLime – Why Abstractions are Useful…

```
bool pendingMsg;
TOS_Msg sendMsg;
event TOS_MsgPtr ReceiveInterestMsg.receive(TOS_MsgPtr m){
  struct InterestMsg* payload = (struct InterestMsg*) m->data;
  if (isRecipient(payload, TOS_LOCAL_ADDRESS))
    insertInterest(payload->sender, payload->type, payload->threshold, payload->timestamp);
  return m;
}
event result_t TemperatureSensor.dataReady(uint16_t reading){
  if (!pendingMsg && matchesInterest(reading)) {
    atomic {
      pendingMsg = TRUE;
      struct DataMsg* payload = (struct DataMsg*) sendMsg->data;
      msg->sender = TOS_LOCAL_ADDRESS;
      msg
      msg
      if
        p
    }
  }
  return SUCCESS;
}
event result_t SendDataMsg.send
  if (msg == sendMsg)
    pendingMsg = FALSE;
  return SUCCESS;
}
```

```
R,sizeof(struct AppMsg),&sendMsg)!= SUCCESS)
```

```
event result_t Tem
  tuple<uint16_t, uint16_t> temperatureValue = newTuple(
                              actualField(TEMPERATURE_READING),
                              actualField(reading));
  call TupleSpace.out(FALSE,TL_LOCAL,&temperatureValue);
  return SUCCESS;
}
```

Maintains an array of current interests

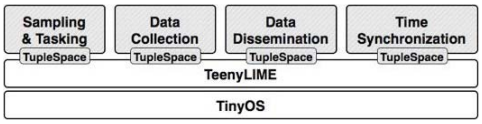
Sends a message if at least one interest matches

Just outputs a tuple, triggering all registered reactions

Data filtering and addressing performed in the application code

Software

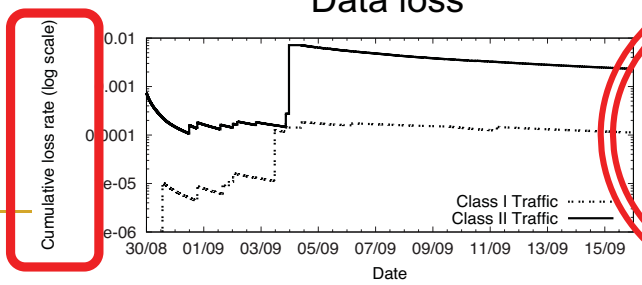
Sampling & Data Collection



- Different classes of traffic
  - **Bursty, high-rate** w/ **strong reliability**
  - **Low-rate** w/ **weak reliability**
  - **Best effort**

Node type	Operating parameters	Typical values
Environmental	Sampling period P # of sampling sessions N	10 min infinite
Deformation	# of samples averaged A Sampling period P # of sampling sessions N	10 10 min infinite
Acceleration	Sampling frequency F Sampling duration D # of sampling sessions N	200 Hz 20 s infinite

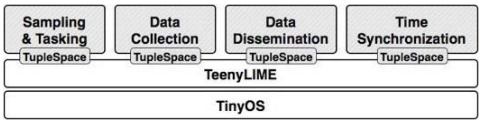
Data loss



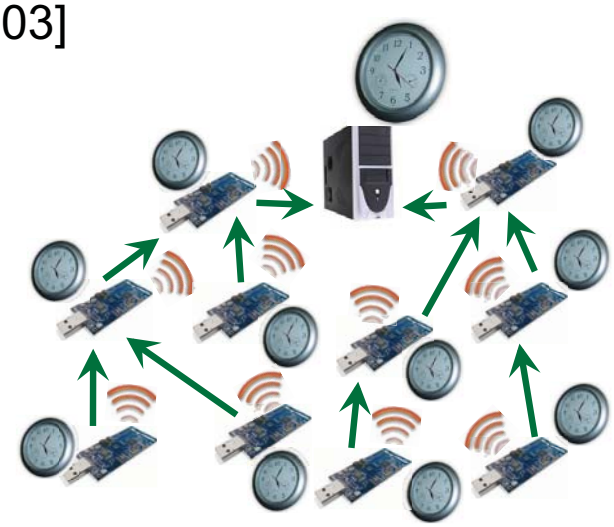
99.99% DELIVERY RATE

Software

Time Synchronization

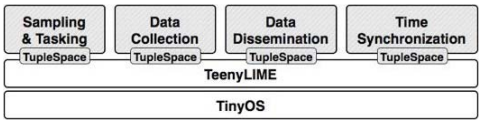


- Hierarchical time synchronization
  - lightweight implementation of TPSN [Ganeriwal et al., SenSys03]
  - on top of TeenyLIME
    - saved 80% LOC
- Lab experiments indicate $\varepsilon < 732$ µs across 12 hop
  - at most 6 hops in Torre Aquila



Software

Tasking & Data Dissemination



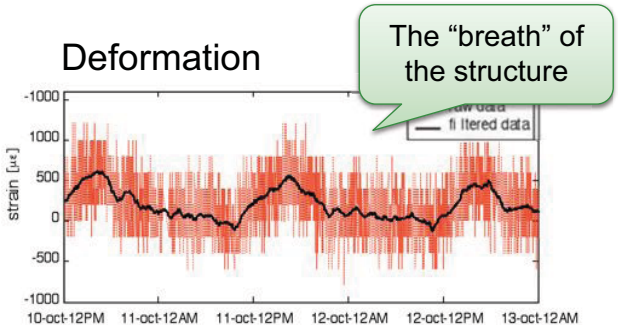
- Ideal sensing parameters not known a priori
- Need online tasking to tune the system operation
  - e.g. with visitors in the tower or during windy days
- Use Trickle-like protocol for ***reliable*** and ***eventual*** delivery of task descriptions

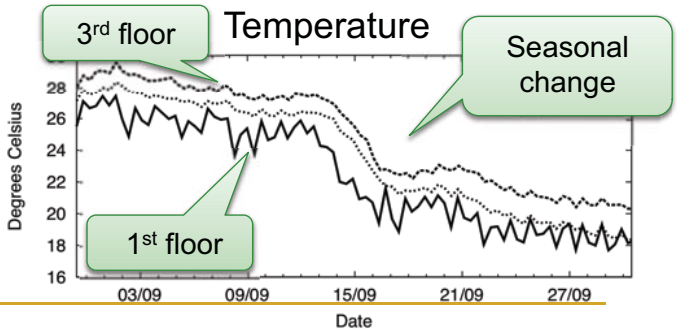
Node type	Operating parameters	Typical values
Environmental	Sampling period P # of sampling sessions N	10 min infinite
Deformation	# of samples averaged A Sampling period P # of sampling sessions N	10 10 min infinite
Acceleration	Sampling frequency F Sampling duration D # of sampling sessions N	200 Hz 20 s infinite

(Preliminary) Data Analysis

Vibrational Modes

Deformation





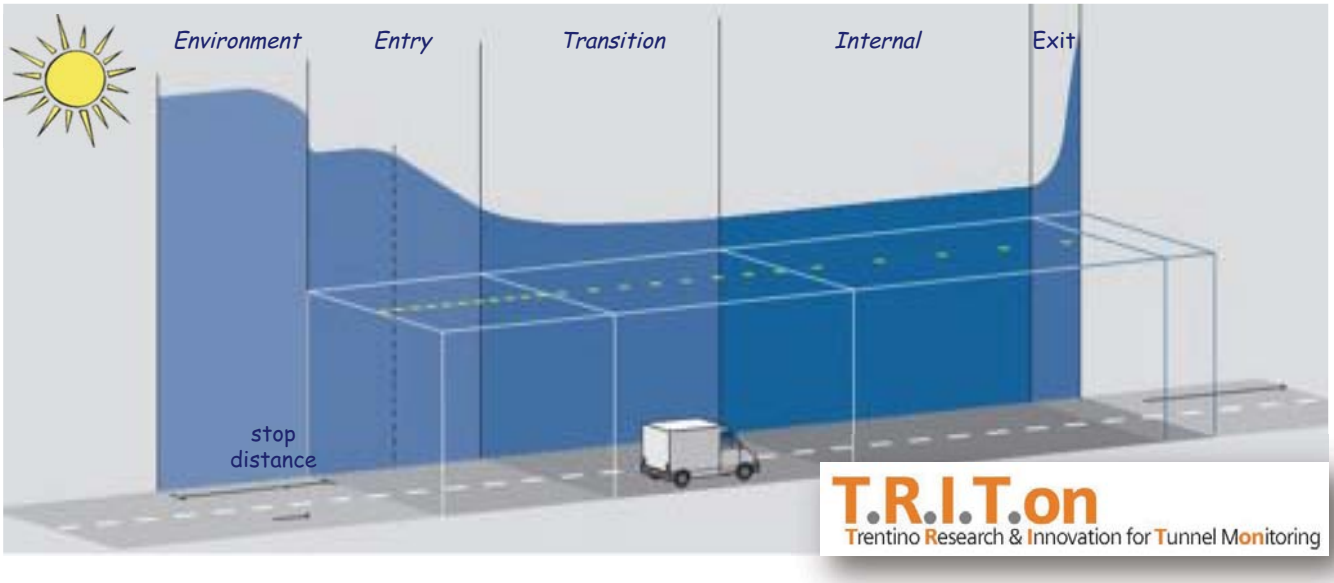
Torre Aquila

- **Data collection reliability: 99.9%**
  - Typical deployments collect 60-70%
  - Support mixed data
    - high rate accelerometer + low rate temperature
- **Lifetime: ~one year** (4 C-cell batteries)
  - Typical deployments last weeks or days
  - Achieved through smart communication

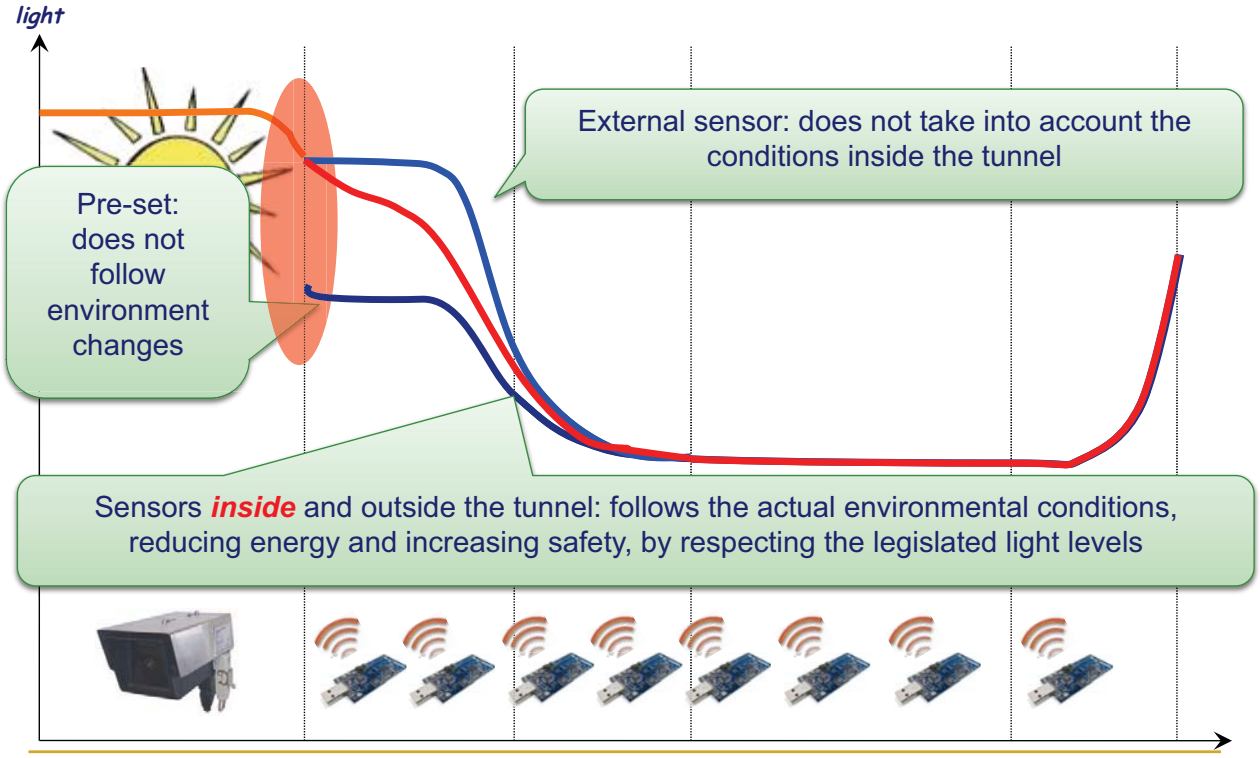
d3s.disi.unitn.it/projects/torreaquila

From a Tower to a Tunnel

- Today the light inside road tunnels is often determined independently from environmental conditions
  - Defined at designed time based on worst case
- Problems: waste of energy and potential security hazard
  - E.g.: large light difference when entering/exiting the tunnel



The Problem



Road Tunnels in Trentino

Data at January 1st, 2007

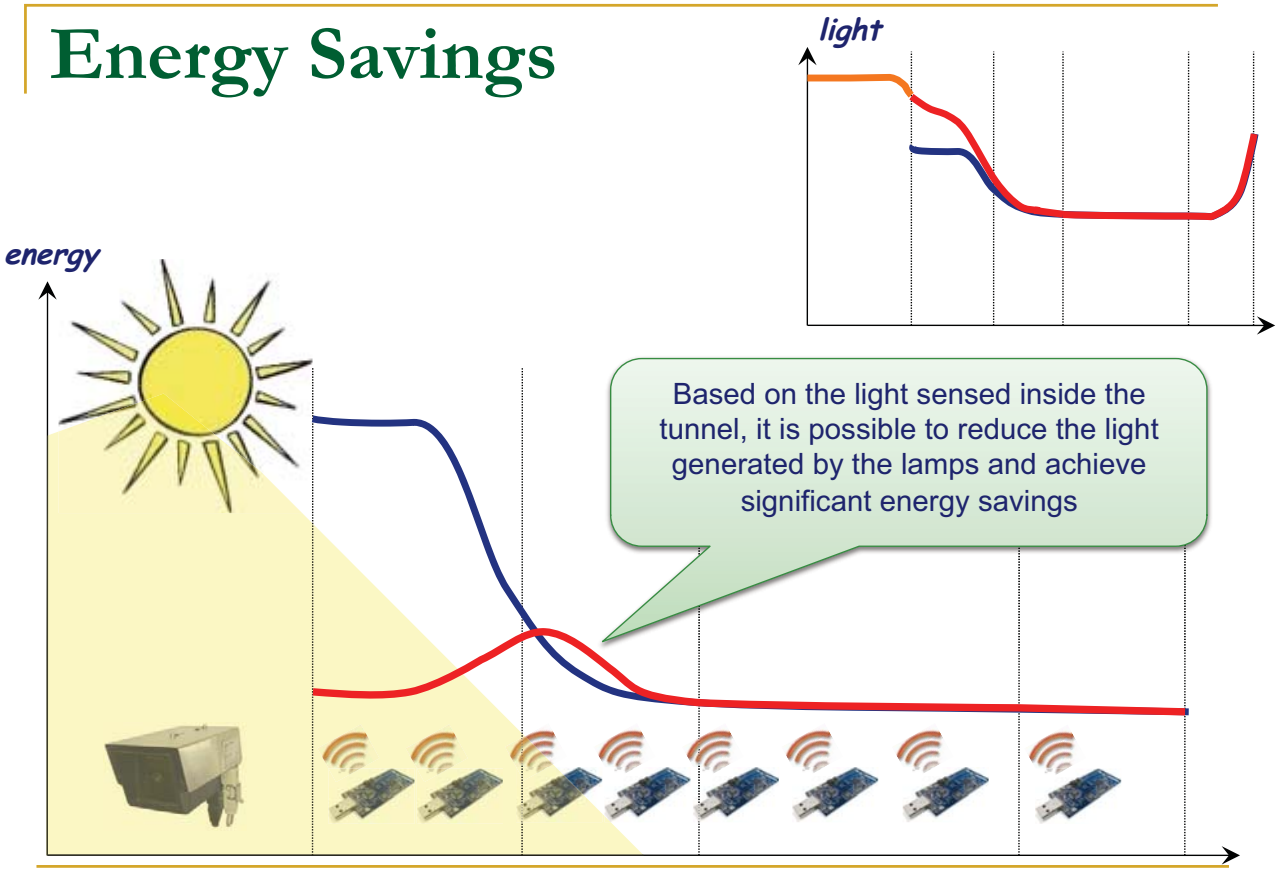
Length (m)	Number of Tunnels	
0 - 25	9	
25 - 75	40	
75 - 125		2.461
125 - 500		11.249
500 - 1.000		9.252
1.000 - 2.000		11.406
> 2.000		13.453
Tot	136	49.784
Tu	Number	Total (m)
	79	9.436
	64	40.348
V entilation	14	24.734

Energy consumption:
~13.500.000 kW/year

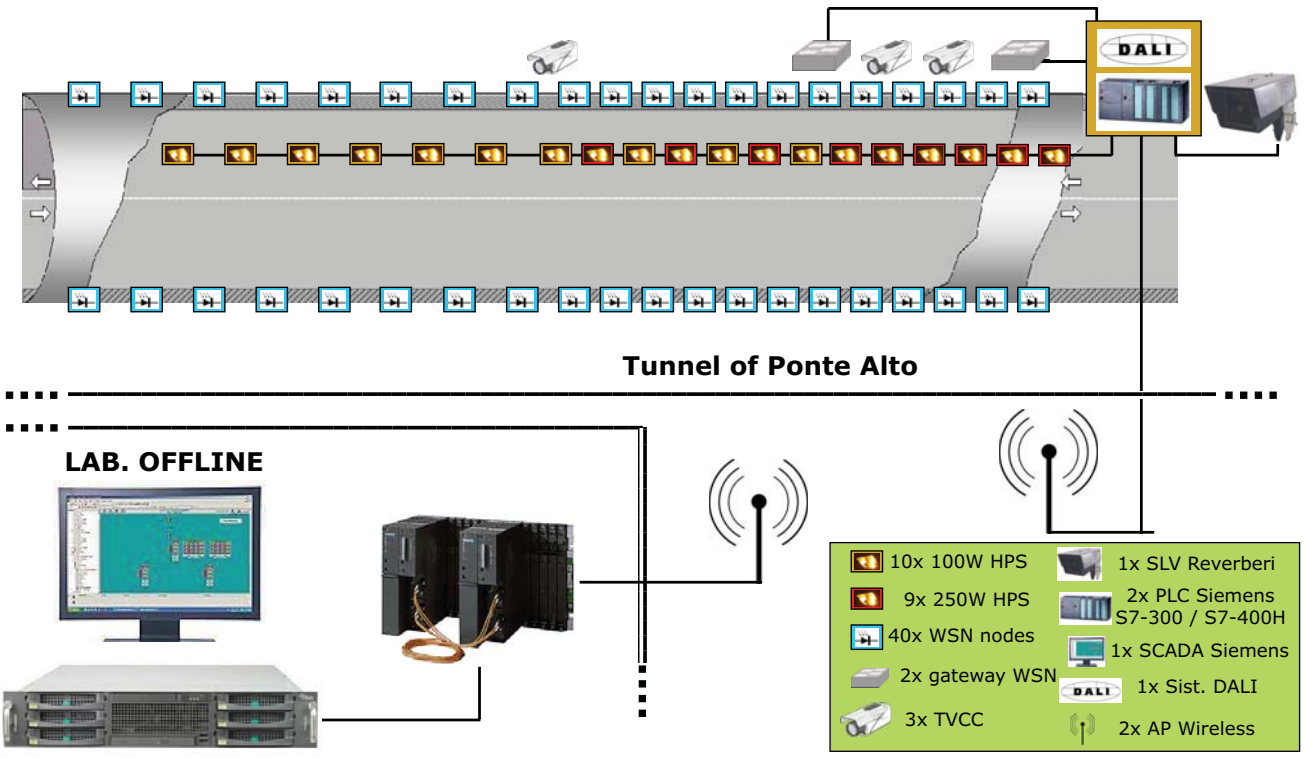
The Question

- Why use wireless in a road tunnel???
  - You have power lines AND ethernet cables for the lights
  - Batteries need to be changed
  - Inside the tunnel, the light doesn't change
- Answers
  - Sensing must be done at 1.7m, where there are no wires
  - Each new attachment point to a wired network costs hundreds of EUR
  - Existing tunnels and short tunnels don't have existing wired networks
  - Internal sensors are sparse and can be used for maintenance

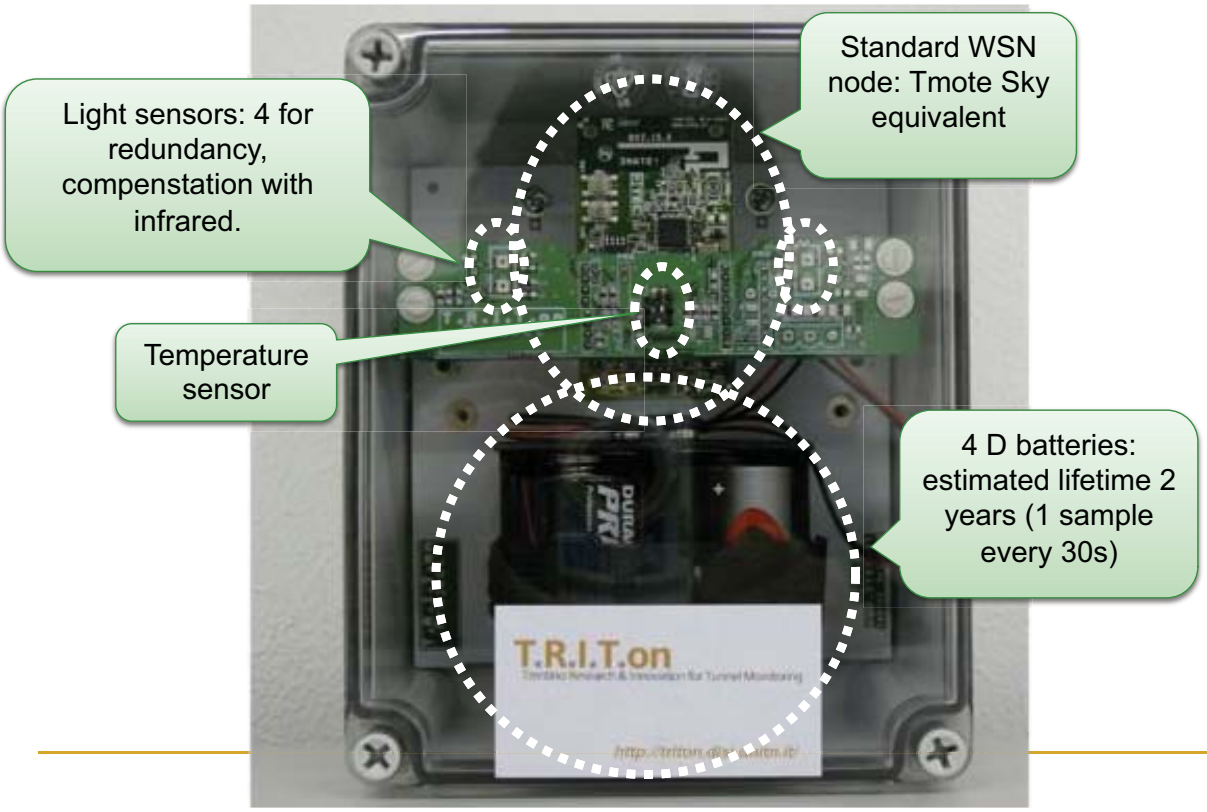
Energy Savings



The Test Site: Ponte Alto

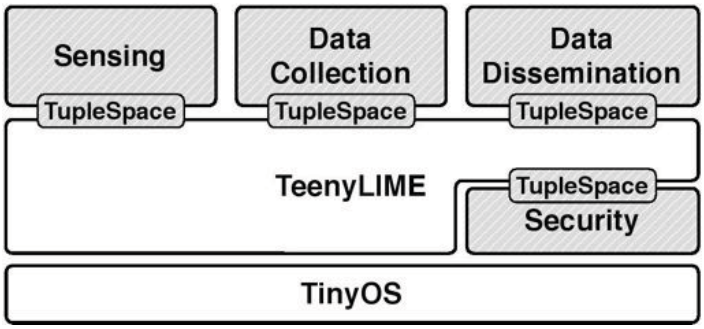


Custom Hardware



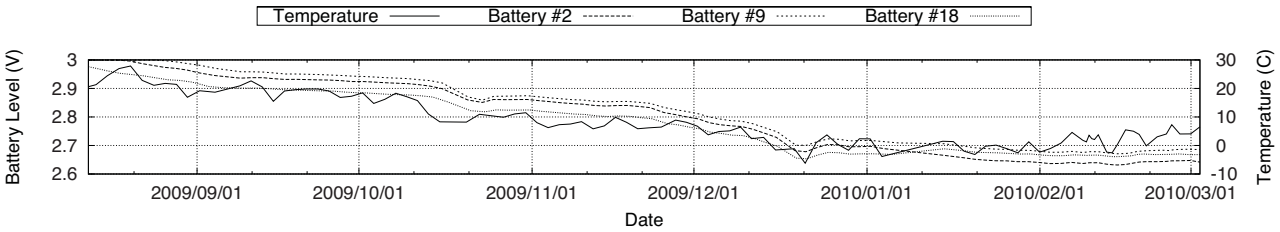
Custom Software

- Developed on *extended* TeenyLIME:
  - abstract operations on FLASH
  - code dissemination
  - secure Communication
- Light data filtered at each node
- Adaptive routing to multiple gateways



Some Results

- Data continuously collected for **7 months** (and more)

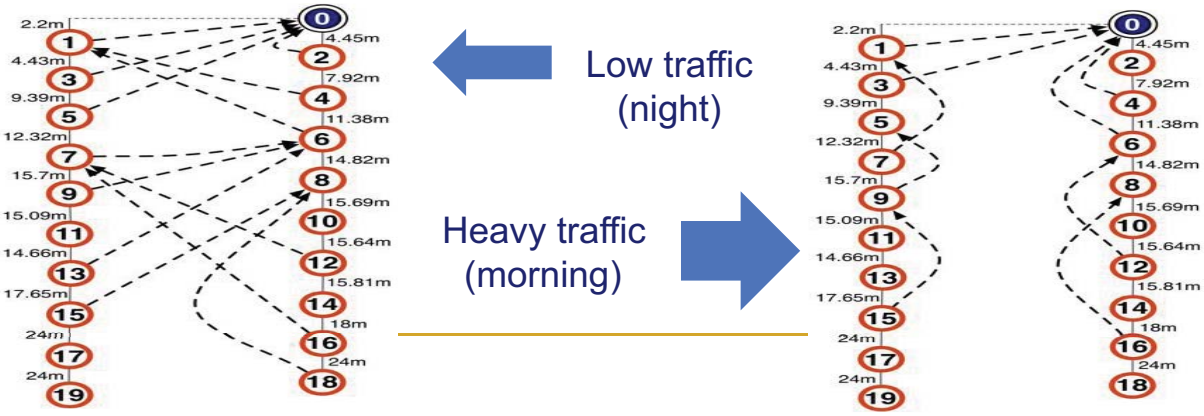


- Data jitter acceptable to the control algorithm
- Light levels successfully maintained in the test tunnel

Example WSN Challenge: *traffic*

Video

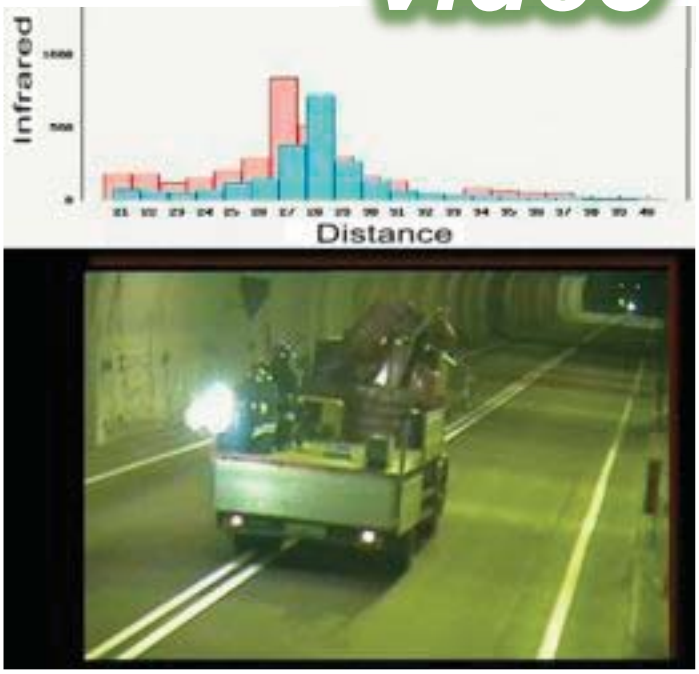
- Natural variations in connectivity require **adaptive routing** to maintain good quality routes
  - Contributing factors: traffic, humidity, faulty nodes
- High reliability and low energy consumption
  - 99.99% data correctly received
  - Multiple gateways for fault tolerance



WSN Opportunity: *Fire Detection*

Video

- Not planned in the project!
  - Once WSN was in place, a small modification allows **fire detection with the IR sensors**
- Can detect
  - Presence of fire and thermal anomalies
  - Locations and trajectories
  - Notably works in the presence of smoke
- Note: this is just a proof of concept
  - But, it is quite promising!



Some Dirty details:

Why This is Not a Sideways Tower

- Built with *the same* middleware layer as Torre Aquila
  - All the components barely fit in memory!
- "Problems"
  - Loose connections between sensor board and communication module
  - Batteries discharge faster in cold weather
  - Boxes get dirty fast!
  - Maintenance in the tunnel in the winter is just not fun

Other WSNs in Trento

- Scenarios
  - Assisted living
  - Vineyards
  - Animal monitoring
- Pre-deployment tools
  - TOSSIM frontend for TeenyLIME
  - Network performance evaluator
- Data visualization
- Reliable MAC
- …