$14.4 trillion

An Open Framework to Deploy Heterogeneous Wireless Testbeds for Cyber-Physical Systems

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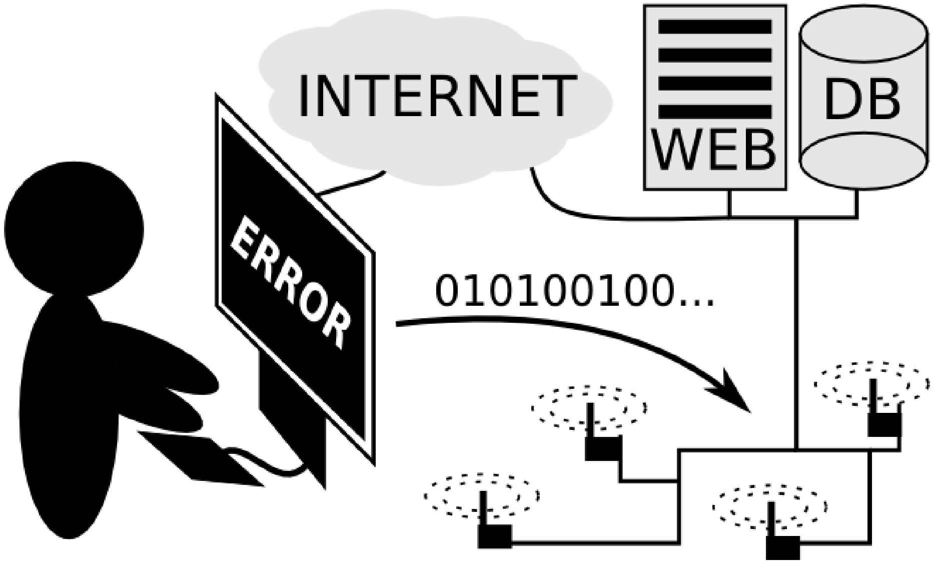
Motivation: Remote Testbeds



Remote Testbeds

moteLab
KanseiGenie
TWIST
NUS National University of Singapore
School of Computing
Communication and Internet Research Lab
Indriya
Wisebed
Senslab

Existing Tools

- Simulators – (TOSSIM, COOJA) are good for early stage development
- Remote Testbeds – are good for the system performance analysis

Remote Testbed Limitations

No support for the interaction with the surrounding environment.

The Rise of Local Testbeds

Benefits of Using Local Testbeds

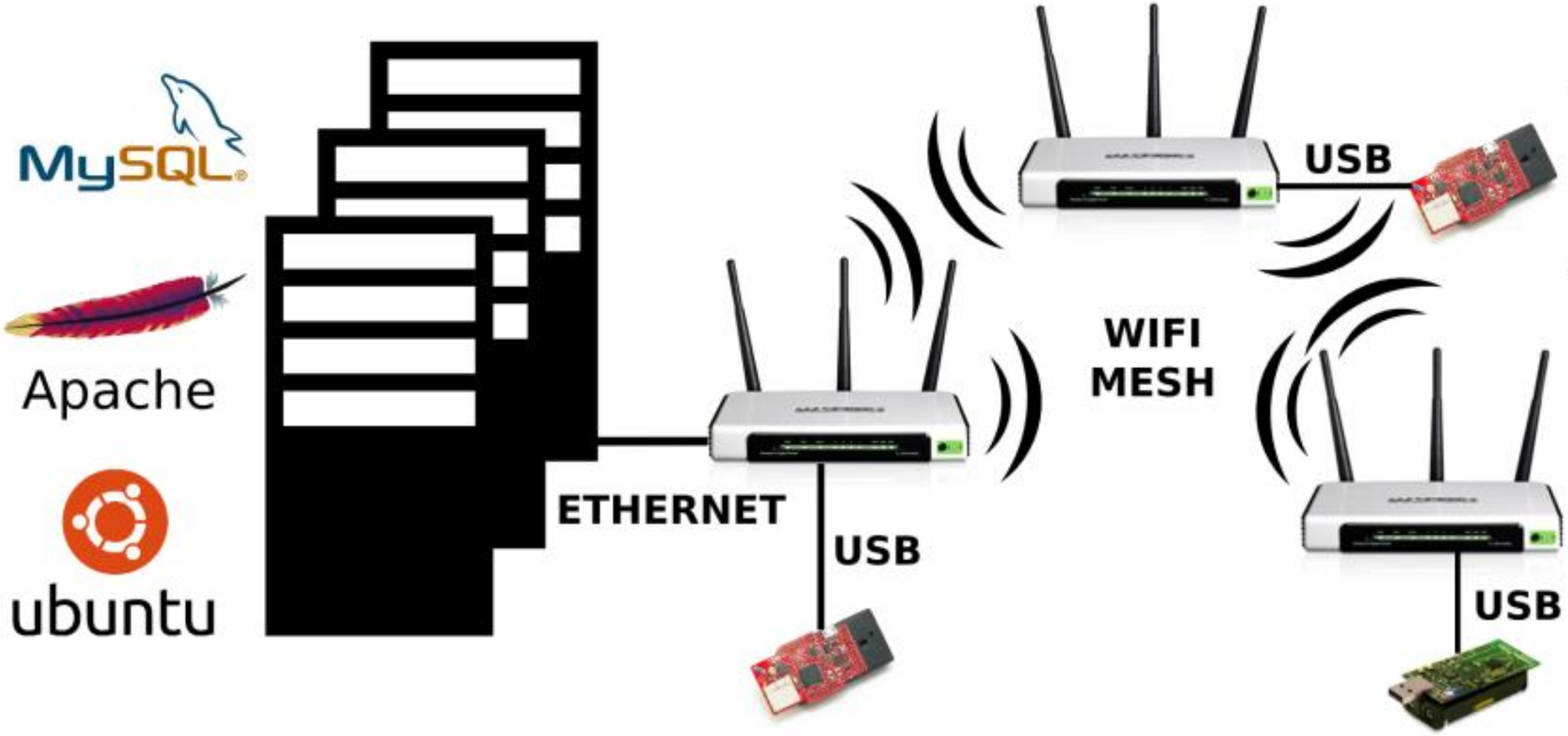
- Better understanding of the application environment
- Quick prototyping
- Build custom, high-performance and high-quality applications
- Improve products’ time-to-market

1. Local testbed framework blueprint

2. Two case studies

3. Experimental evaluation

Contribution: Open Testbed Framework



Server Back-End

- Monitors testbeds status
- Provides User Interface

Backbone Network

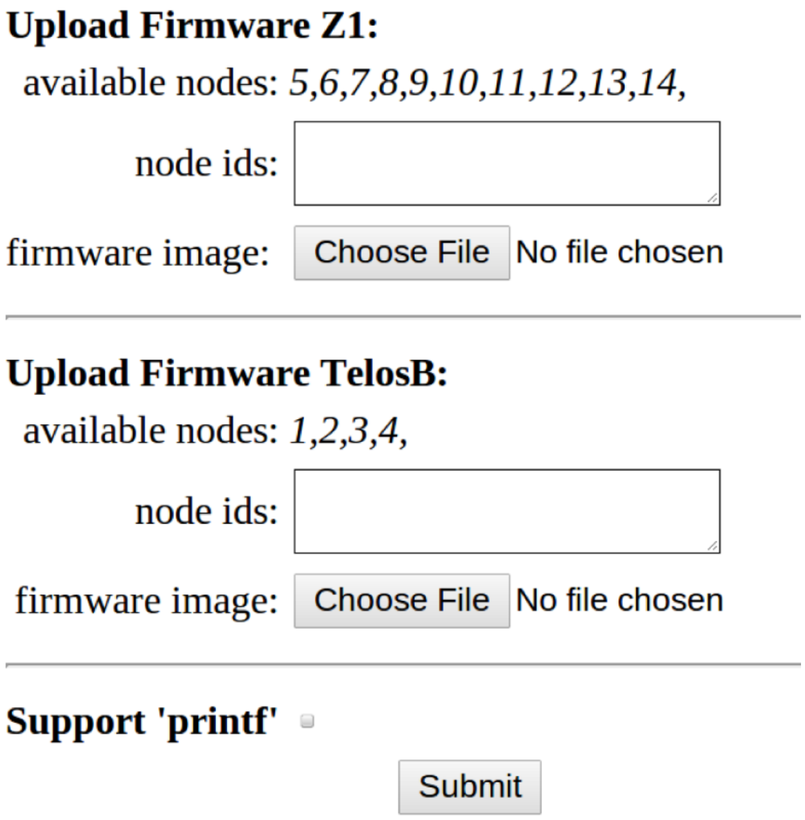
- Connects the Server Back-End with the sensor motes

Management Unit

- Provide mechanisms to reprogram firmware of the sensor motes

Open Testbed Framework: Server Back-End

Firmware Upload Interface



Upload Firmware Z1:

available nodes: *5,6,7,8,9,10,11,12,13,14,*

node ids:

firmware image: Choose File No file chosen

Upload Firmware TelosB:

available nodes: *1,2,3,4,*

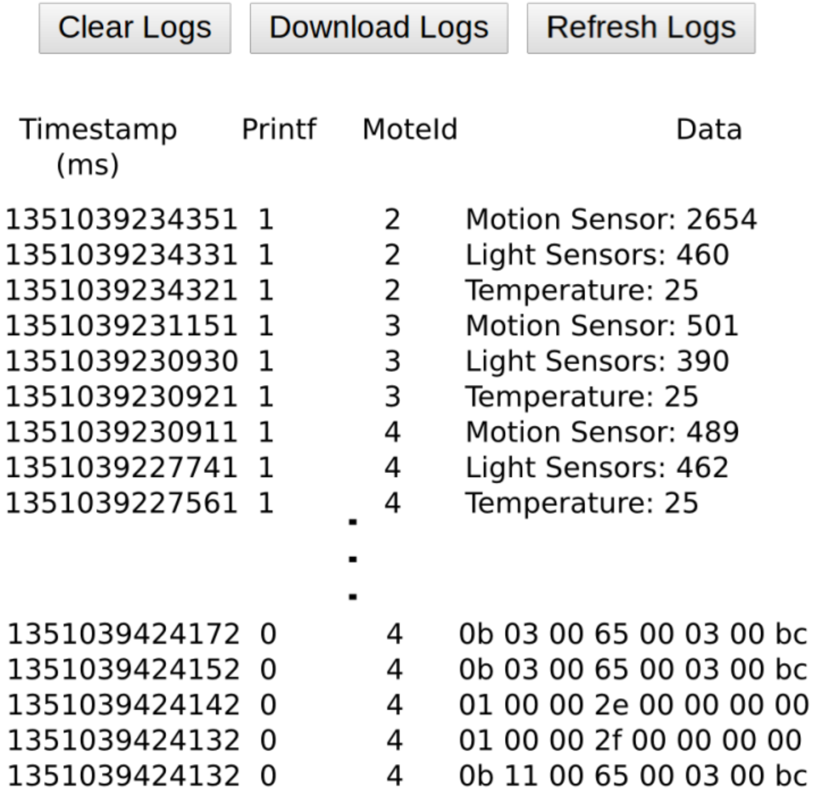
node ids:

firmware image: Choose File No file chosen

Support 'printf' □

Submit

Online Sensors' Logs Monitoring



Clear Logs | Download Logs | Refresh Logs

```
 Timestamp      Printf   MoteId             Data
   (ms)

1351039234351  1          2      Motion Sensor: 2654
1351039234331  1          2      Light Sensors: 460
1351039234321  1          2      Temperature: 25
1351039231151  1          3      Motion Sensor: 501
1351039230930  1          3      Light Sensors: 390
1351039230921  1          3      Temperature: 25
1351039230911  1          4      Motion Sensor: 489
1351039227741  1          4      Light Sensors: 462
1351039227561  1          4      Temperature: 25
                        .
                        .
                        .
1351039424172  0          4     0b 03 00 65 00 03 00 bc
1351039424152  0          4     0b 03 00 65 00 03 00 bc
1351039424142  0          4     01 00 00 2e 00 00 00 00
1351039424132  0          4     01 00 00 2f 00 00 00 00
1351039424132  0          4     0b 11 00 65 00 03 00 bc
```

Open Testbed Framework: Backbone Network

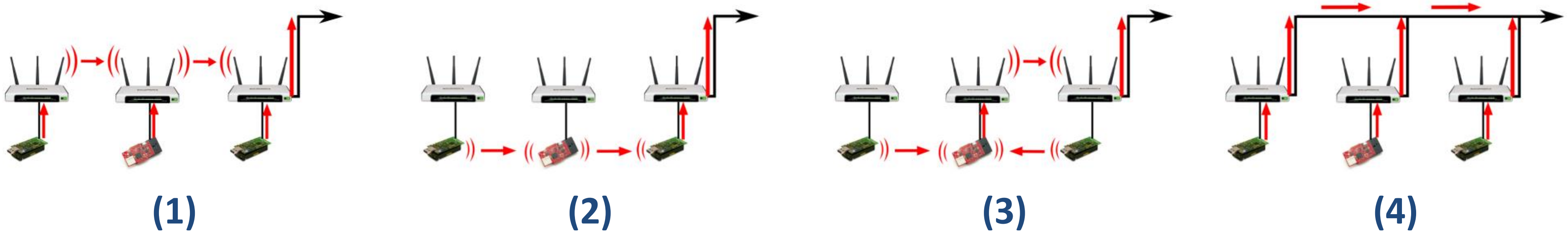
Hardware

- WiFi Routers
  - OpenWRT Linux
  - Ad-hoc mesh network

- TelosB and Zolertia Z1
  - Powered through USB on the router

Support Multiple Sensor Data Collection Methods:

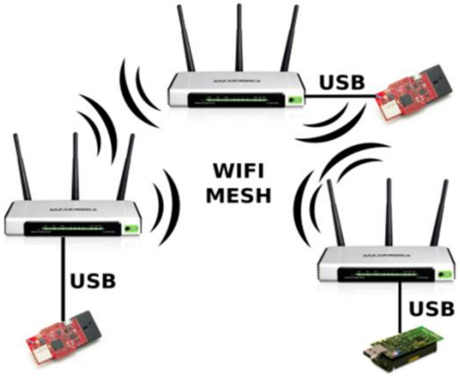
1. WiFi ad-hoc network
2. Low-Power Wireless Network (LPWN)
3. Two Tier network of LPWN and WiFi
4. Ethernet



Open Testbed Framework: Testbed Management Unit

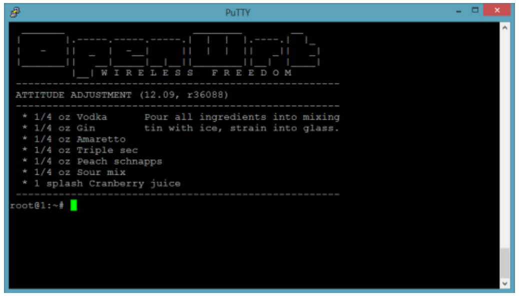
1. Server Back-End Tools

- Firmware verification
- Firmware copies
- Nodes status monitoring
- Logs collection



2. Backbone Network

- Secured Encryption
- Routing Monitoring

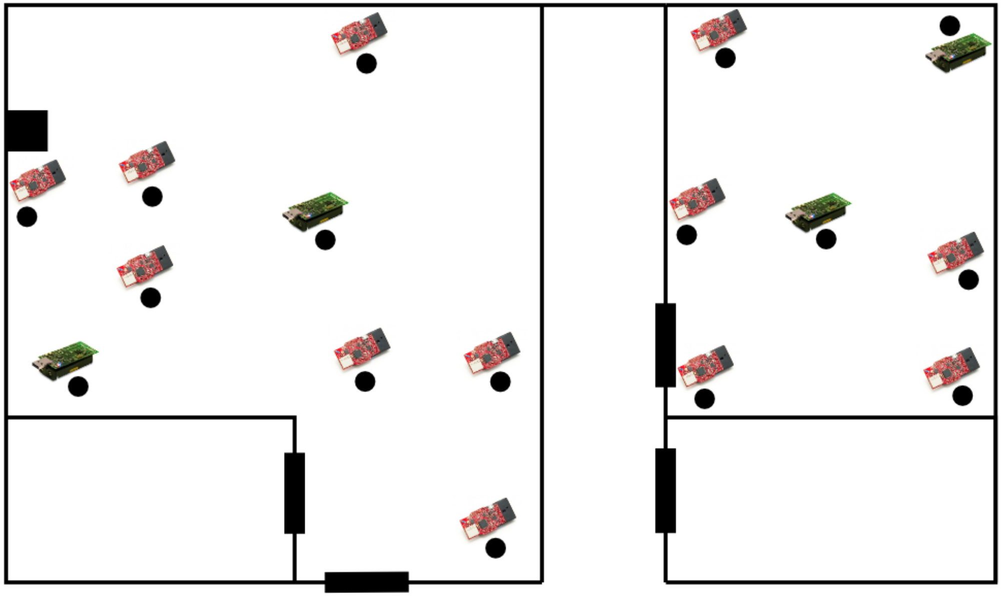


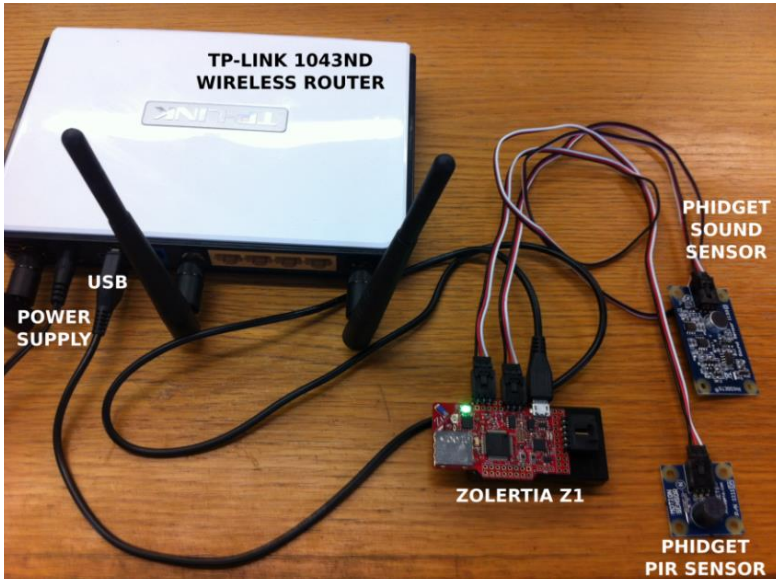
```
  _______                     ________        __
 |       |.-----.-----.-----.|  |  |  |.----.|  |_
 |   -   ||  _  |  -__|     ||  |  |  ||   _||   _|
 |_______||   __|_____|__|__||________||__|  |____|
          |__| W I R E L E S S   F R E E D O M
 -----------------------------------------------------
 ATTITUDE ADJUSTMENT (12.09, r36088)
 -----------------------------------------------------
  * 1/4 oz Vodka      Pour all ingredients into mixing
  * 1/4 oz Gin        tin with ice, strain into glass.
  * 1/4 oz Amaretto
  * 1/4 oz Triple sec
  * 1/4 oz Peach schnapps
  * 1/4 oz Sour mix
  * 1 splash Cranberry juice
 -----------------------------------------------------
root@1:~#
```

3. Router Tools

- Firmware Installation
- Mote monitoring

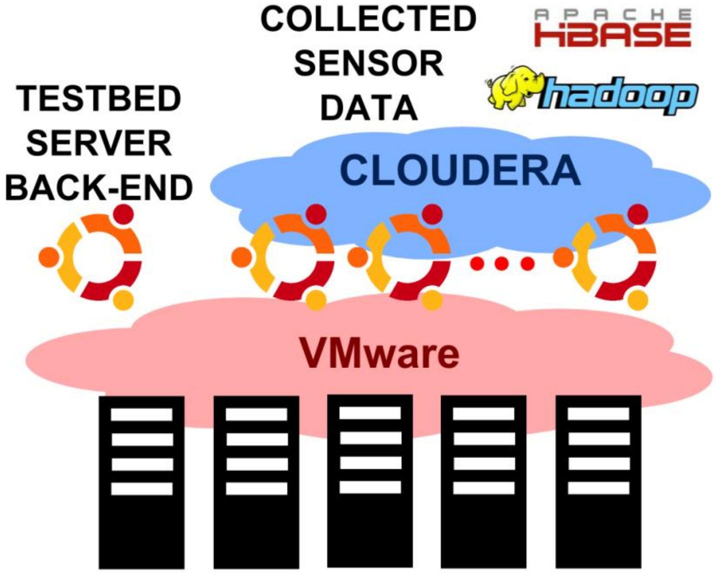
Indoor Office Space Deployment



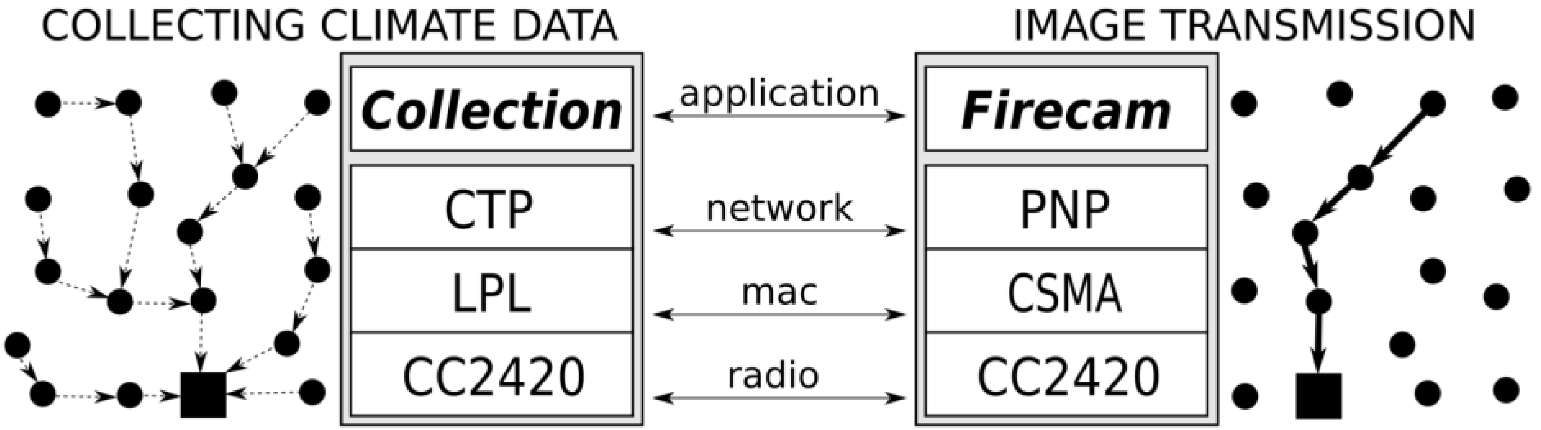


Columbia University

- Office Area
- Cost $169 per node
- Applications: Occupancy Estimation, and Smart Building

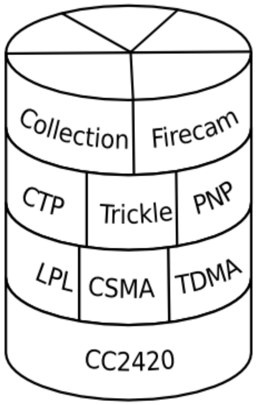


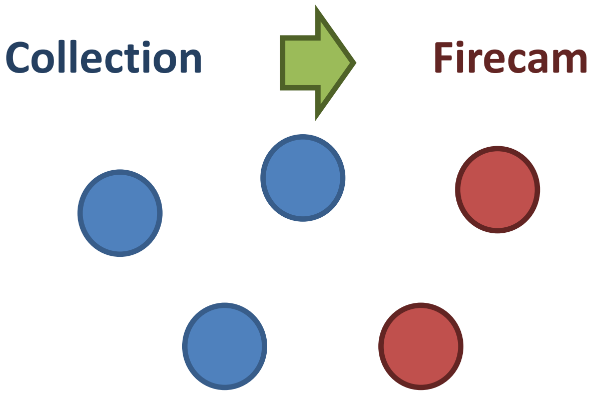
Fennec Fox Framework



- *collecting climate data*
- *streaming series of pictures*

```
configuration Monitoring { collection(1024, NODE, 107)
                          ctp(107)  lpl (100, 10)   cc2420(1)}
configuration Emergency {firecam(28), pnp(),
                                  csma(0,0)      cc2420(0)}
event fire {smoke = ON }
event check {timer = 30 sec}
from Monitoring goto Emergency when fire
from Emergency goto Monitoring when check
start Monitoring
```



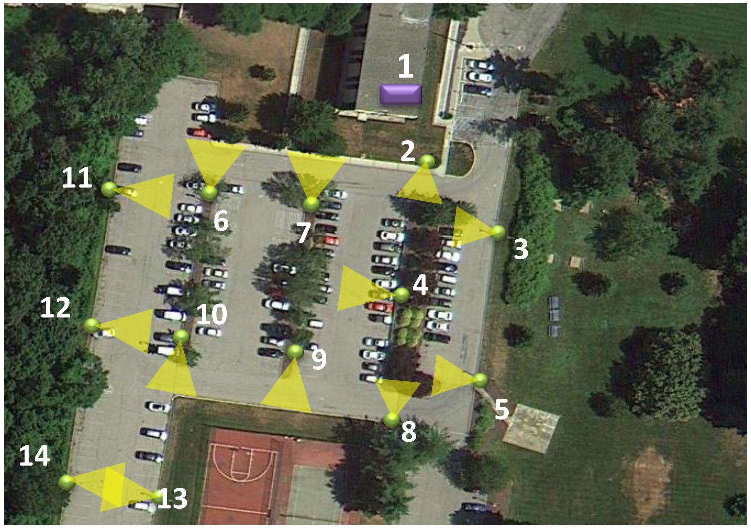


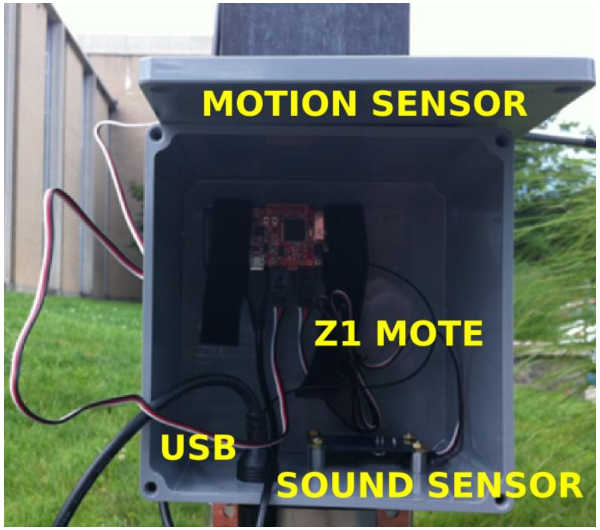
Programming Language Swift Fox

Reconfigurable Protocol Stack

Application Context-Switch Across the Network

Outdoor Parking Lot Deployment





Philips Research North America

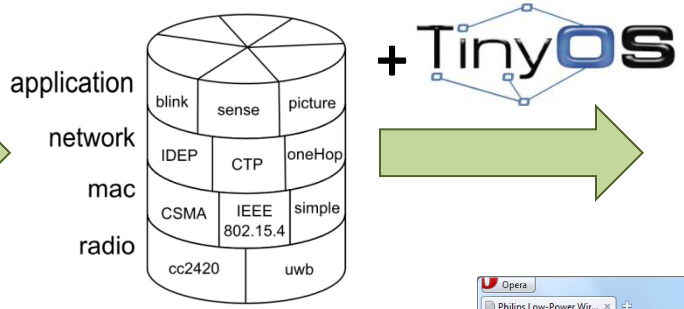
- Outdoor Parking Lot
- Cost $282 per node ($113 for boxes)
- Applications: Intelligent Outdoor Lighting

Testbed Usage Flow

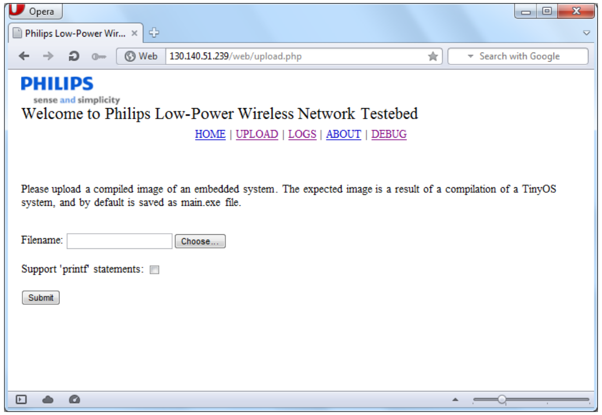
Swift Fox Program

```
configuration demo {
                philips004(200, 1, NODE, 2)
                # Application Params:
                #       * sensing delay
                #       * delay's scale (1 means ms, 1024 means seconds)
                #       * data source (this is mote's ID)
                #       * data destination (this is mote's ID - the gateway)
                ctp(2)
                # Network Params:
                #       * gateway's address
                nullMac()
                # simple IEEE 802.15.4 - no params
                cc2420(2, 26, 31, 0, 0, 10, 10, 1, 1, 1)}
                # Radio Params:
                #       * gateway's address
                #       * Radio's Channel (IEEE 802.15.4)
                #       * Radio's TX Power (31 -> 0db)
                #       * Duty-Cycle Remote Wakeup Interval
                #       * Duty-Cycle Delay After Receive
                #       * Random Backoff Interval (jiffies)
                #       * Min Random Backoff (jiffies)
                #       * Use Acknowledgements
                #       * Use Clear Channel Assesment
                #       * Use Cyclic-Redundancy Check
start demo
```

Fennec Fox Framework



Firmware Image



Welcome to Philips Low-Power Wireless Network Testebed

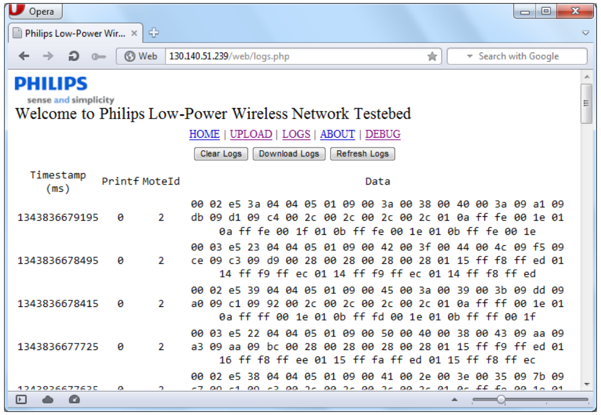
HOME | UPLOAD | LOGS | ABOUT | DEBUG

Please upload a compiled image of an embedded system. The expected image is a result of a compilation of a TinyOS system, and by default is saved as main.exe file.

Filename: [Choose...]

Support 'printf' statements: □

[Submit]

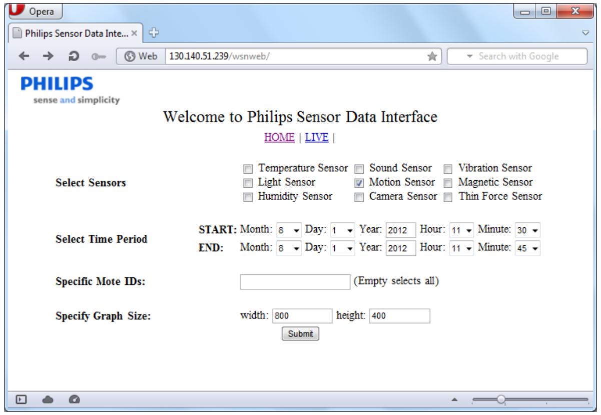


Welcome to Philips Low-Power Wireless Network Testebed

HOME | UPLOAD | LOGS | ABOUT | DEBUG

[Clear Logs] [Download Logs] [Refresh Logs]

```
  Timestamp
    (ms)      Printf MoteId                       Data
                          00 02 e5 3a 04 04 05 01 09 00 3a 00 38 00 40 00 3a 09 a1 09
1343836679195   0      2  db 09 d1 09 c4 00 2c 00 2c 00 2c 00 2c 01 0a ff fe 00 1e 01
                             0a ff fe 00 1f 01 0b ff fe 00 1e 01 0b ff fe 00 1e
                          00 03 e5 23 04 04 05 01 09 00 42 00 3f 00 44 00 4c 09 f5 09
1343836678495   0      2  ce 09 c3 09 d9 00 28 00 28 00 28 00 28 01 15 ff f8 ff ed 01
                             14 ff f9 ff ec 01 14 ff f9 ff ec 01 14 ff f8 ff ed
                          00 02 e5 39 04 04 05 01 09 00 45 00 3a 00 39 00 3b 09 dd 09
1343836678415   0      2  a0 09 c1 09 92 00 2c 00 2c 00 2c 00 2c 01 0a ff ff 00 1e 01
                             0a ff ff 00 1e 01 0b ff fd 00 1e 01 0b ff ff 00 1f
                          00 03 e5 22 04 04 05 01 09 00 50 00 40 00 38 00 43 09 aa 09
1343836677725   0      2  a3 09 aa 09 bc 00 28 00 28 00 28 00 28 01 15 ff f9 ff ed 01
                             16 ff f8 ff ee 01 15 ff fa ff ed 01 15 ff f8 ff ec
                          00 02 e5 38 04 04 05 01 09 00 41 00 2e 00 3e 00 35 09 7b 09
```



Welcome to Philips Sensor Data Interface

HOME | LIVE |

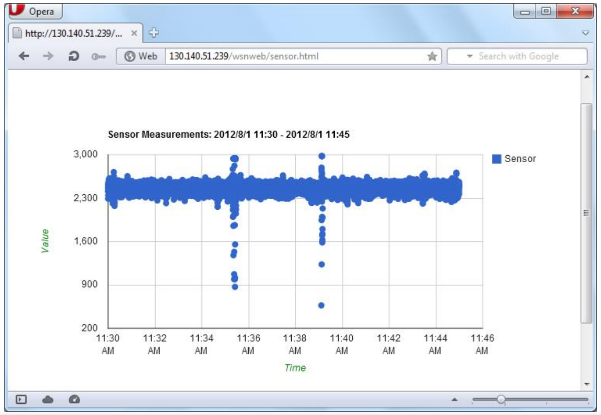
Select Sensors □ Temperature Sensor □ Sound Sensor □ Vibration Sensor □ Light Sensor ☑ Motion Sensor □ Magnetic Sensor □ Humidity Sensor □ Camera Sensor □ Thin Force Sensor

Select Time Period
START: Month: 8 Day: 1 Year: 2012 Hour: 11 Minute: 30
END: Month: 8 Day: 1 Year: 2012 Hour: 11 Minute: 45

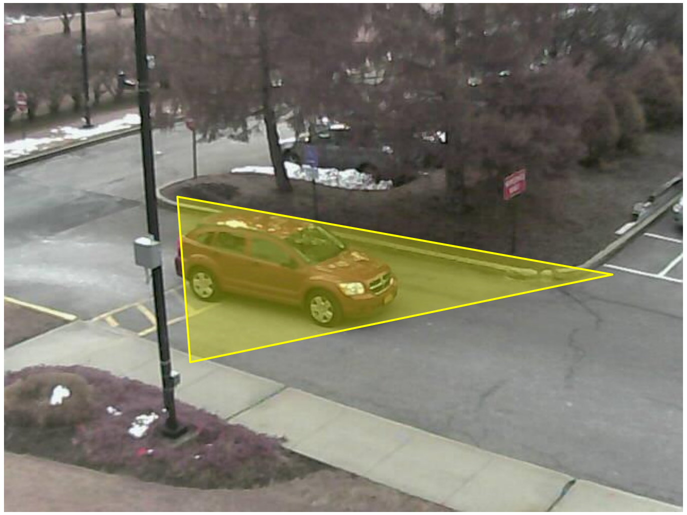
Specific Mote IDs: (Empty selects all)

Specify Graph Size: width: 800 height: 400

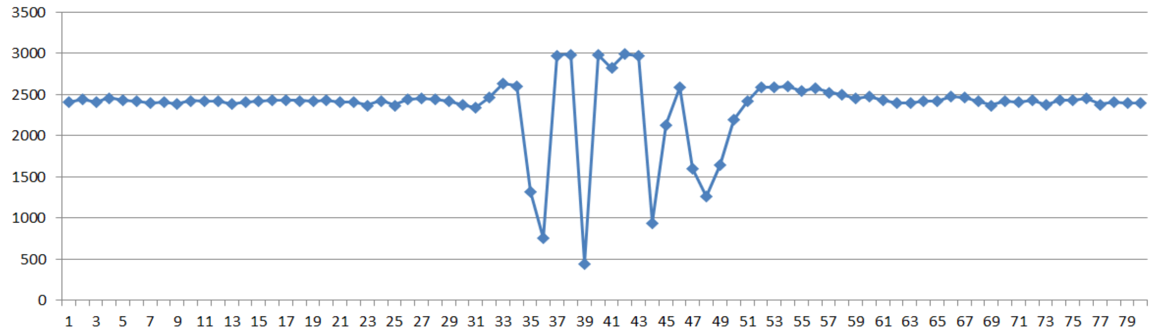
[Submit]

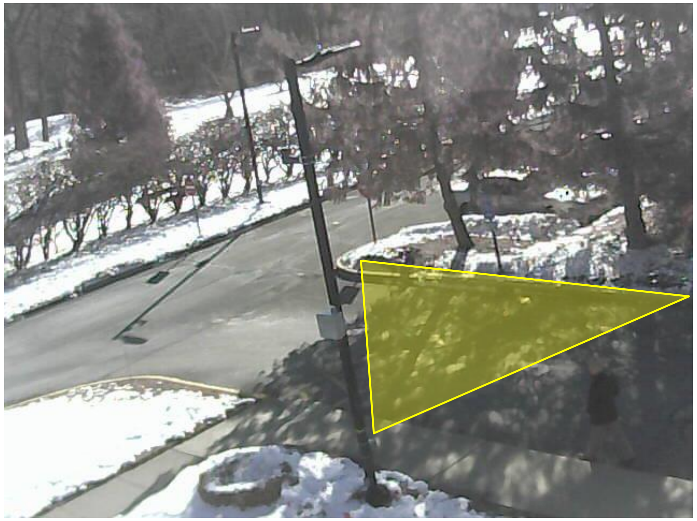


Philips Parking Lot Motion Detection

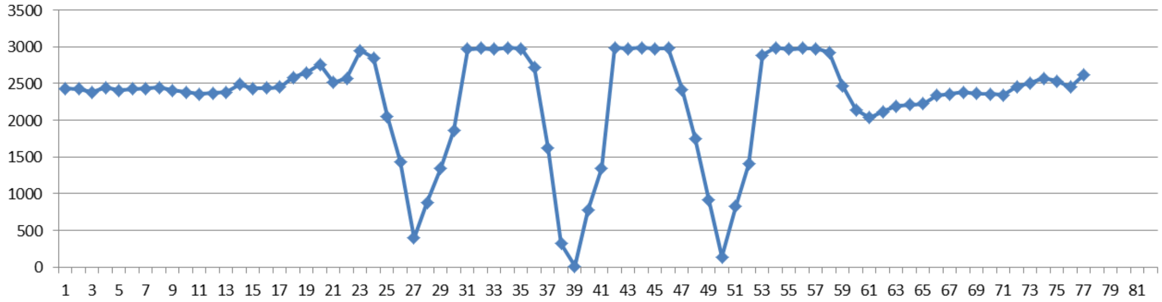


Motion Detection Triggered by a Car





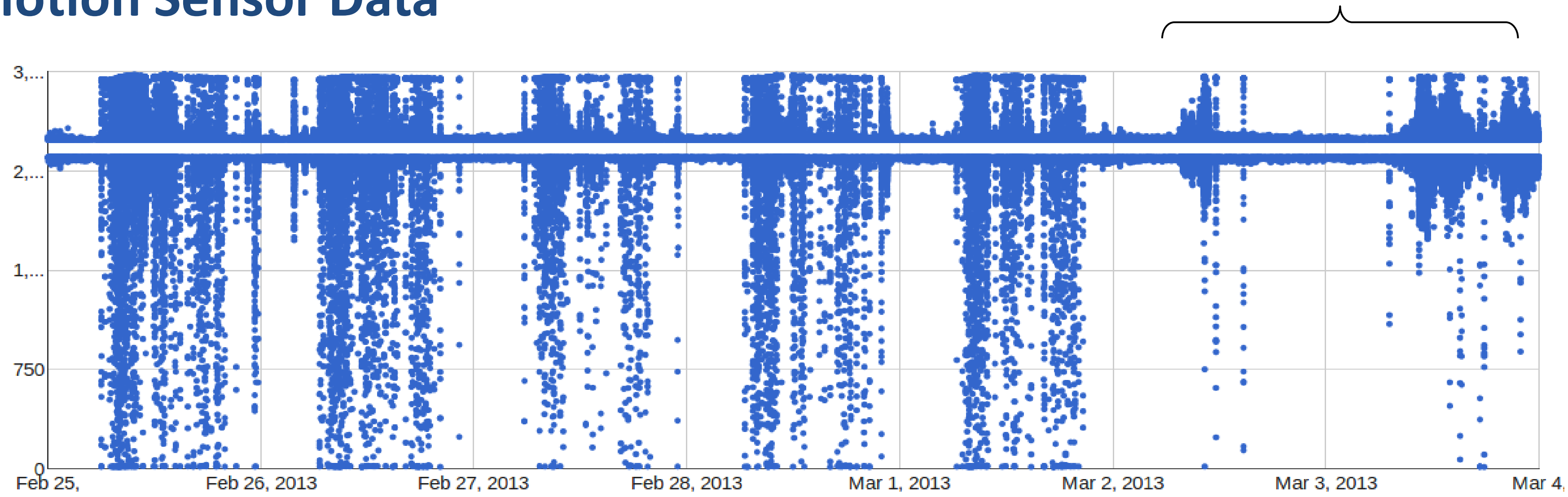
Motion Detection Triggered by a Person

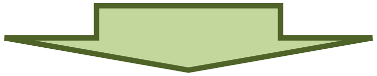


Sensor Data Processing for Traffic Estimation

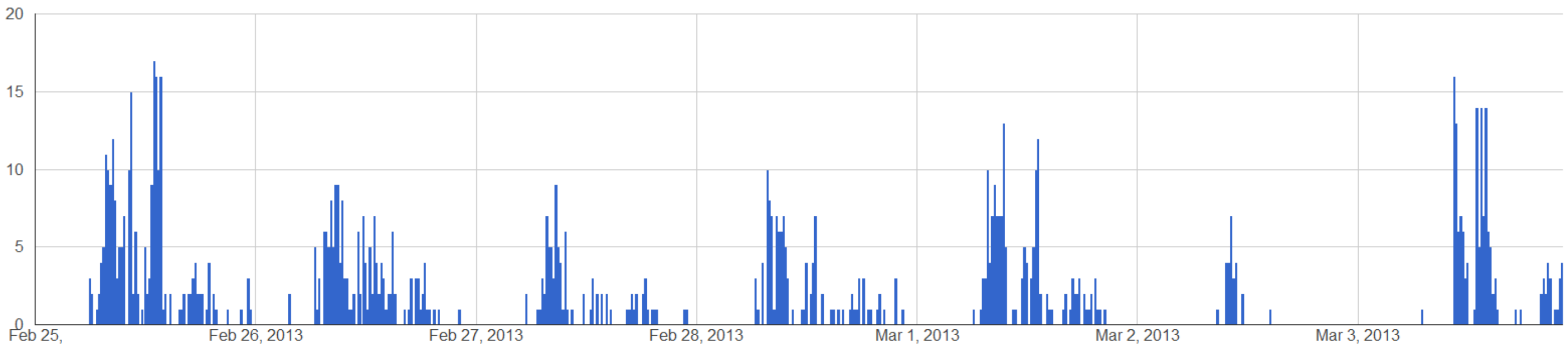
Motion Sensor Data

Weekend

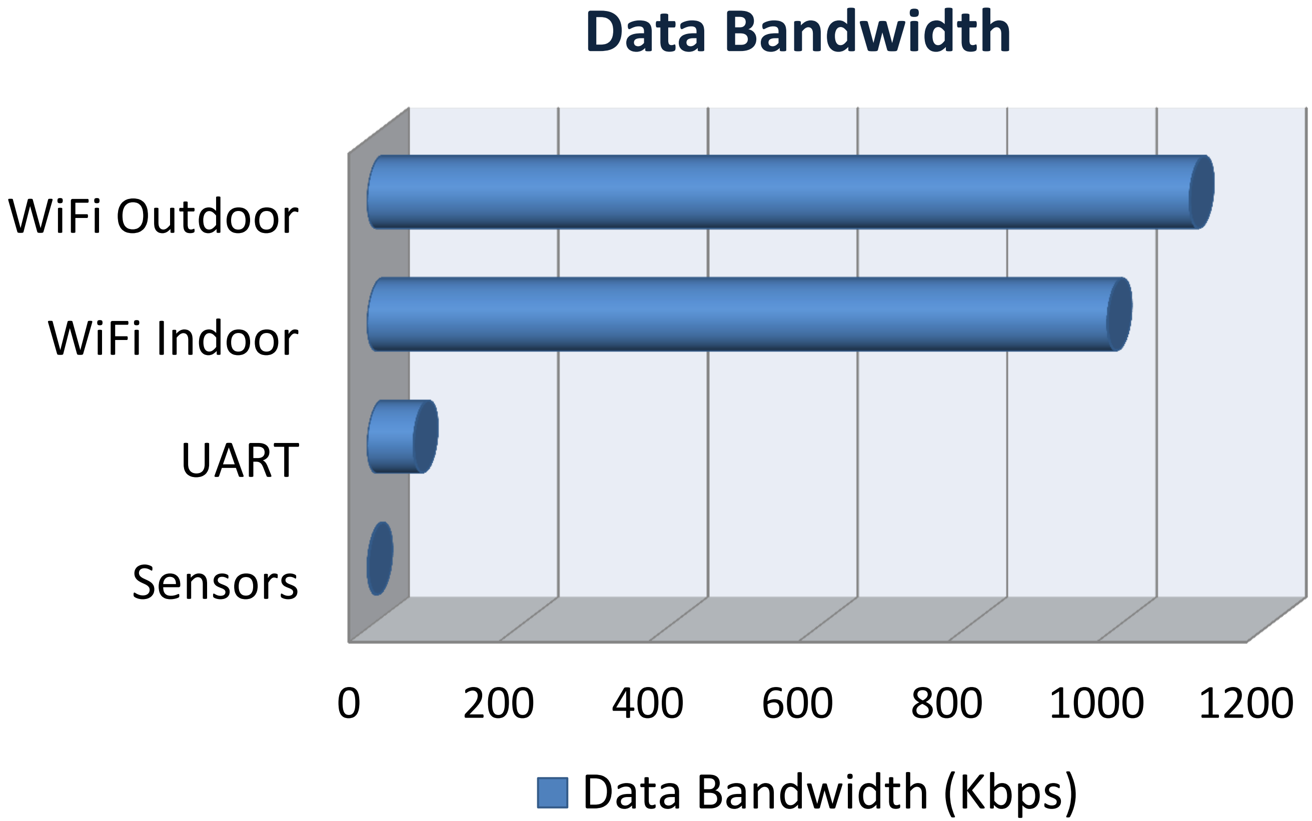




Detections counter every 15 minutes



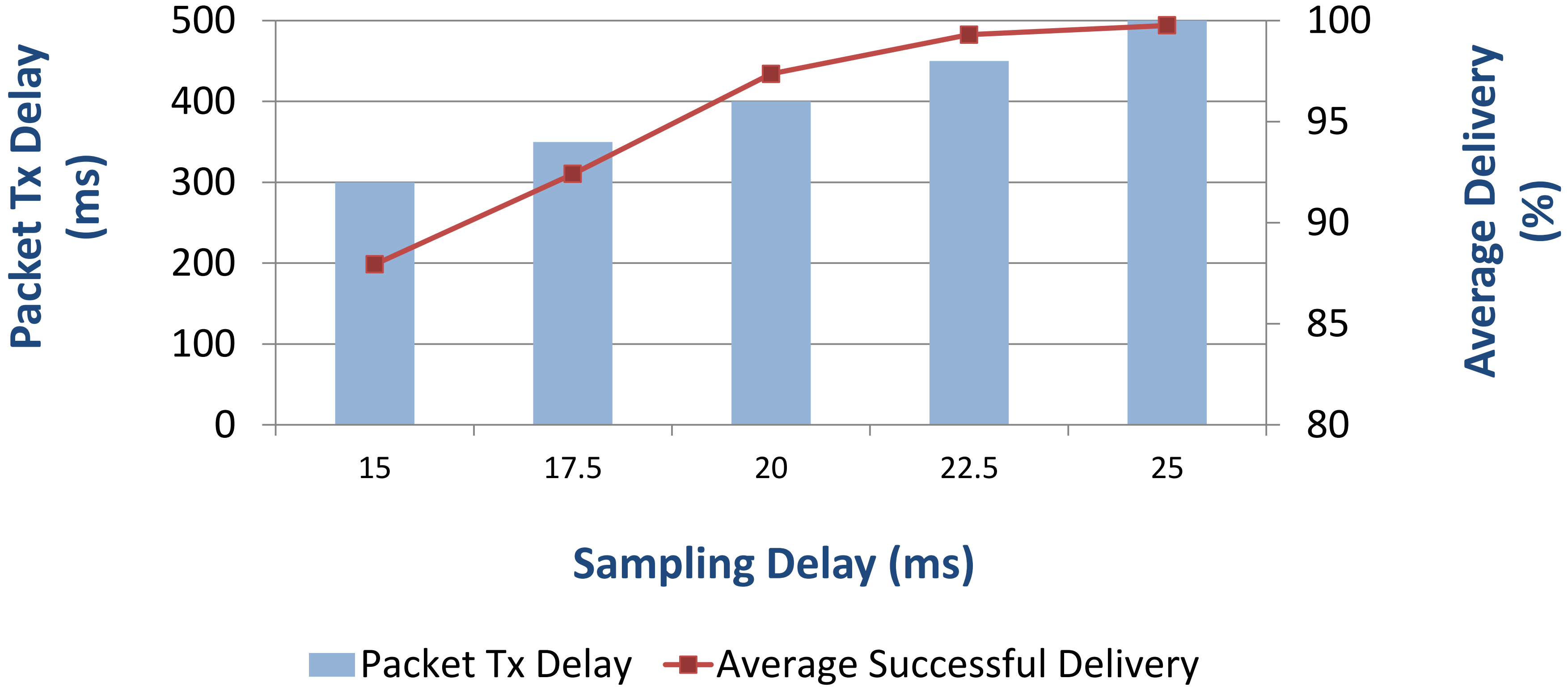
Testbed Evaluation: Hardware Limitation



WiFi-based Backbone is Sufficient to Collect Sensor Measurements

The wireless communication bandwidth across the ad-hoc network is orders of magnitude larger than the maximum rates at which motes collect sensors' samples

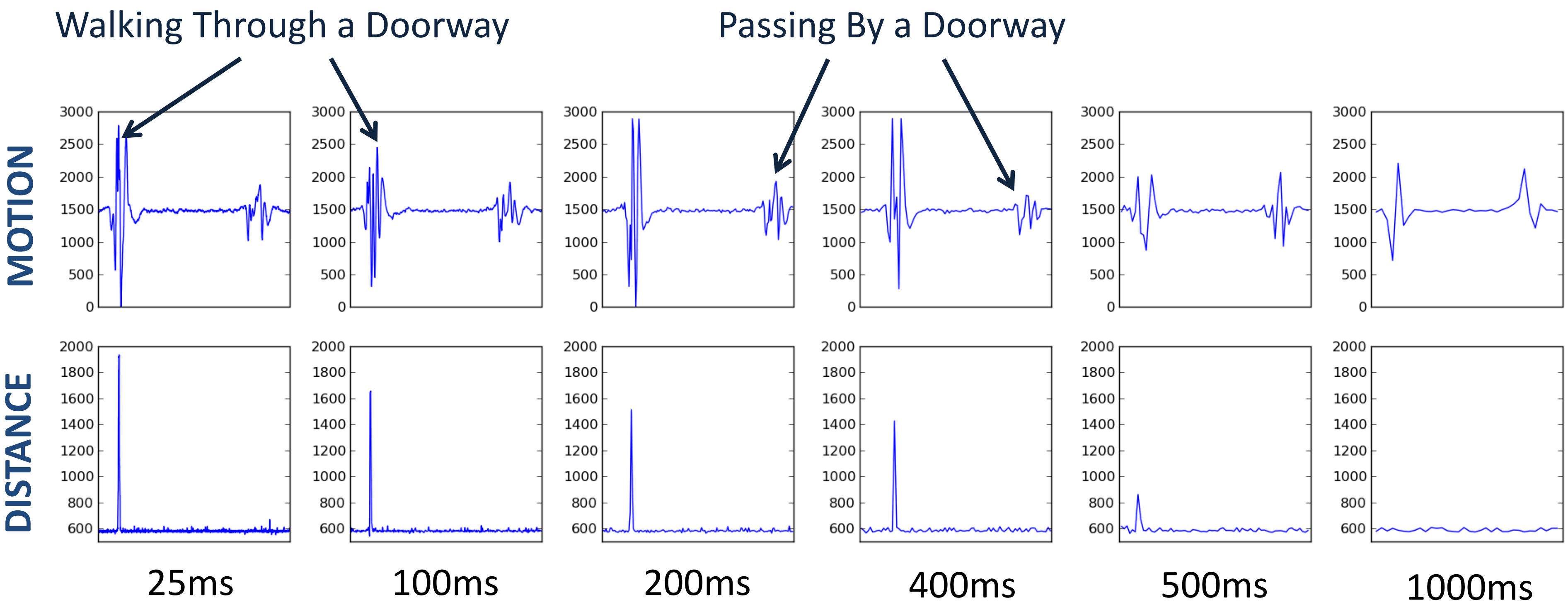
Testbed Evaluation: Data Collection Through LPWN



Collecting Data From 17-Node Testbed

Collection Tree Protocol can successfully collect data when every mote samples one sensor measurements at 50Hz (every 20 ms) or lower frequency.

Testbed Evaluation: Event Detection



Walking Through a Doorway

Passing By a Doorway

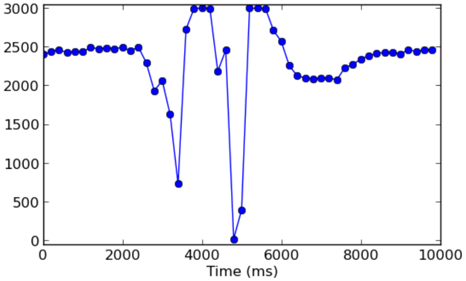
Experimental Setup

- Motion and distance sensors mounted on top of the door frame, facing downward
- A person **walks through the doorway** and next **passes by the door**

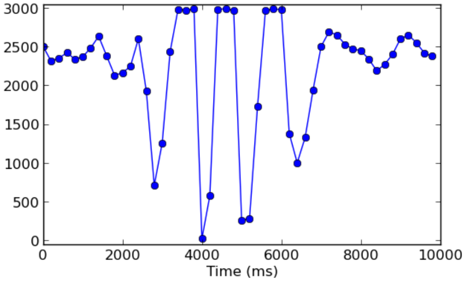
Experimental Results

- Motion sensor detects both events
- Distance sensor only detects walks through the door
- 2.5Hz (every 400ms) is the minimum sampling frequency sufficient to detect and to distinguish the two events

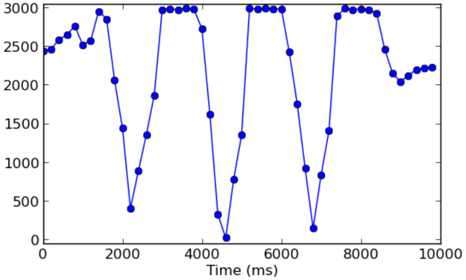
Testbed Evaluation: Event Classification



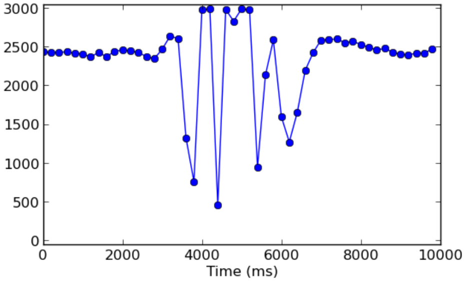
Office Doorway



Parking - Person (6ft)



Parking - Person (12ft)



Parking - Car

- Outdoor, distinguish people from cars based on event length
- The length of an event reveals the distance to a person
- Deployment context helps in classifying events

Conclusion

Open Testbed Framework enables development of Wireless Sensor Networks, Cyber-Physical Systems and Internet of Things

- Framework Building Blocks
- Indoor and Outdoor Case Studies
- Experimental Evaluation

Open Source Code:

- GitHub: https://github.com/mszczodrak/otf

Thank You,

Marcin Szczodrak - msz@cs.columbia.edu