Object Monitoring Using Low Power Consumption Embedded Devices and Heterogeneous Wireless Sensor Networks

Doctoral Thesis in Computer Science by

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ESF EIROPAS SOCIĀLAIS FONDS

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IEGULDĪJUMS TAVĀ NĀKOTNĒ

LATVIJAS UNIVERSITĀTE ANNO 1919

Riga, 31.08.2015.

Outline of talk

- Hypothesis
- General Model of Object Monitoring
- Wild Animal Monitoring Using WSN
- Heterogeneous Toolkit for Real-Time Edutainment
- Web Services for Low Power Consumption WSNs
- Conclusions
- Track Record

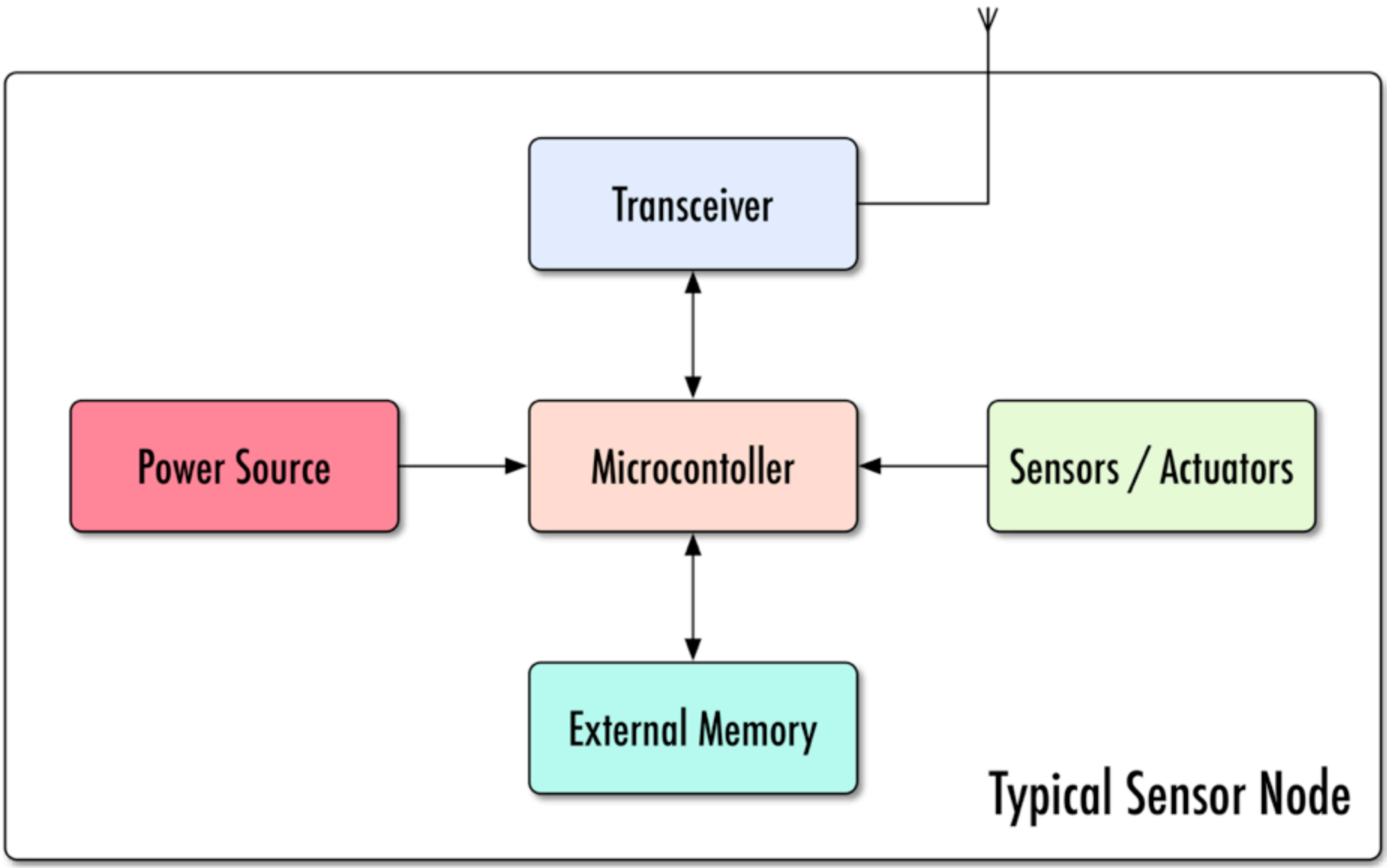
Hypothesis

- It’s possible to describe a method of creating embedded sensor device based on externally provided preconditions and restrictions and with energy consumption, information processing and availability optimized for the particular purpose
- Optimization is heuristic multi-criteria based
- Optimum criteria value is based on expert's opinion

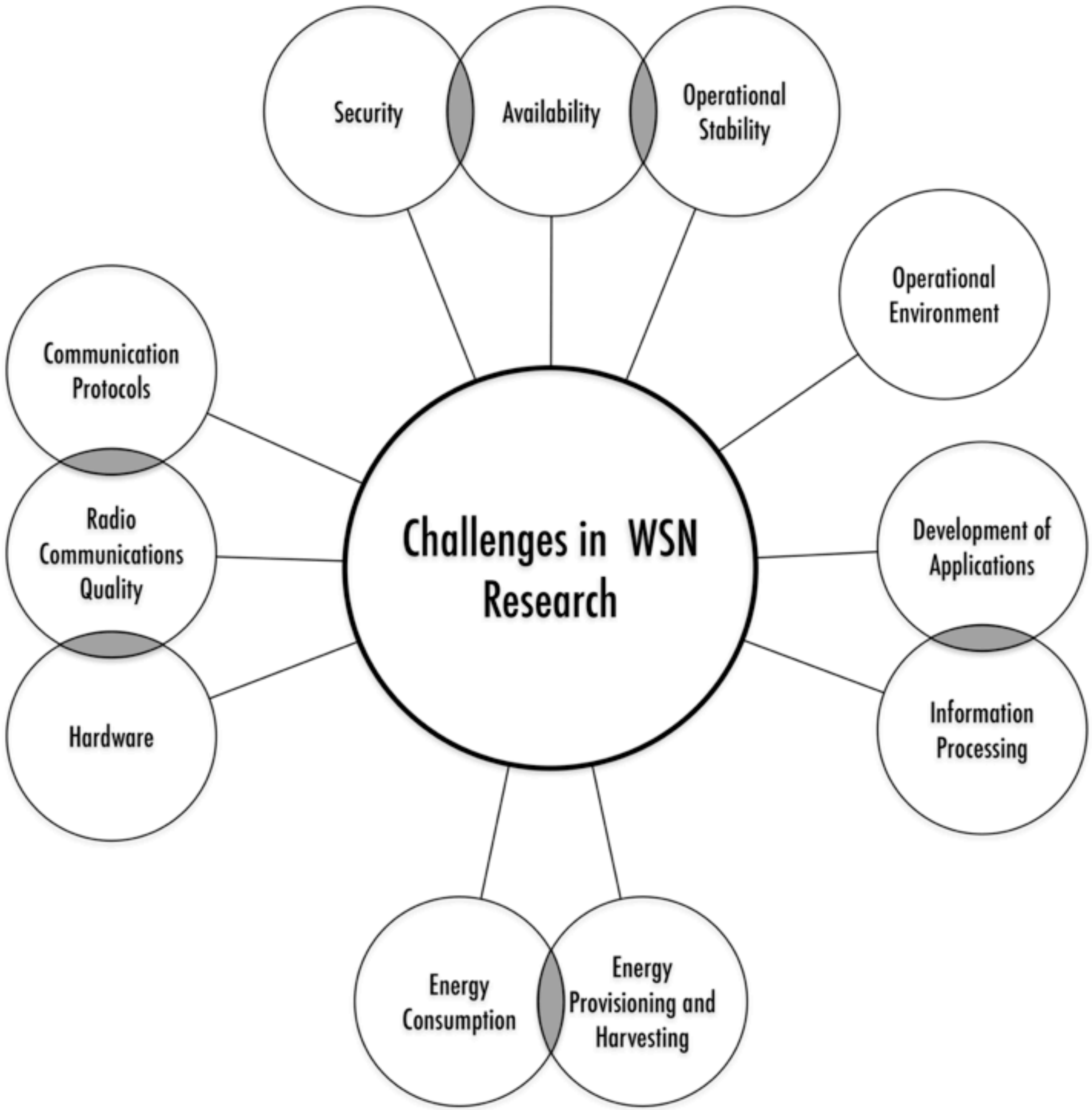
- Thesis consists of 4 major parts
- First part describes General Model of Object Monitoring
- Next 3 parts of Thesis describes approbations of general method in wild animal monitoring, edutainment and environmental monitoring

Part 1

General Model of Object Monitoring



Transceiver
Power Source
Microcontoller
Sensors / Actuators
External Memory
Typical Sensor Node

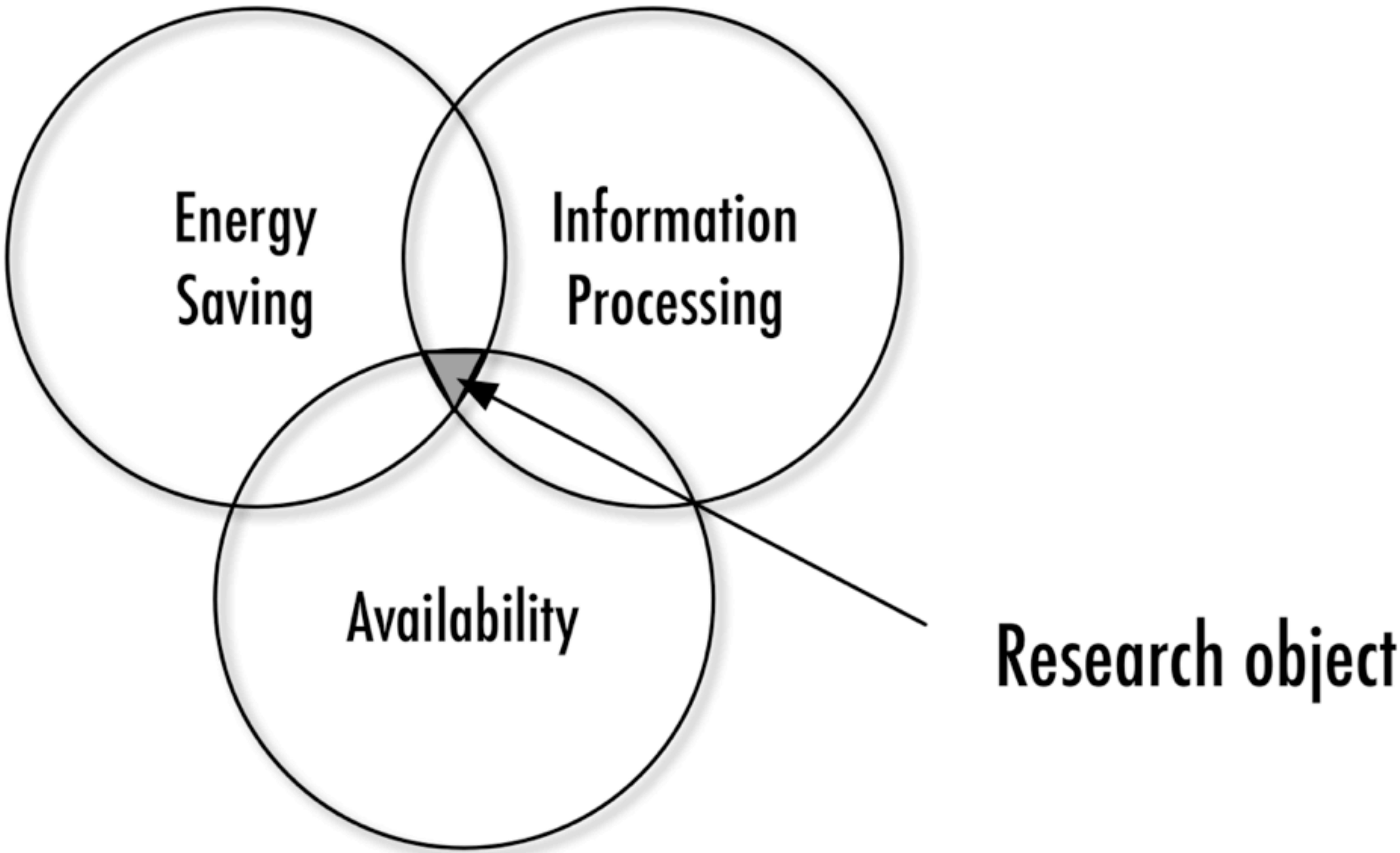

Security
Availability
Operational Stability
Operational Environment
Communication Protocols
Radio Communications Quality
Hardware
Challenges in WSN Research
Development of Applications
Information Processing
Energy Consumption
Energy Provisioning and Harvesting

Subject of Monitoring (Who?)	Object of Monitoring (What?)
Mobile	Mobile
Mobile	Static
Static	Mobile
Static	Static

Assessment of WSN Challenge Complexity Against Realization

Challenge	Weight	Models								Total
		M-M		M-S		S-M		S-S		
		C	V	C	V	C	V	C	V	
Hardware	1	0,5	0,5	0,5	0,5	0,75	0,75	0,75	0,75	2,5
Quality of radio communications	2	1	2	0,75	1,5	0,75	1,5	0,5	1	6
Communication protocols	2	1	2	0,75	1,5	0,75	1,5	0,25	0,5	5,5
Security	3	0,25	0,75	0,25	0,75	1	3	1	3	7,5
Availability	4	1	4	1	4	0,25	1	0,25	1	**10**
Operational stability	3	1	3	1	3	0,5	1,5	0,5	1,5	9
Operational environment	2	0,75	1,5	0,5	1	0,25	0,5	0	0	3
Application development	1	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,5	1,5
Information processing	4	1	4	0,75	3	0,5	2	0,5	2	**11**
Energy provisioning or harvesting	3	0,75	2,25	0,75	2,25	0,5	1,5	0,5	1,5	7,5
Energy saving	5	1	5	1	5	0,75	3,75	0,75	3,75	**17,5**
Total	**30**		**25,25**		**22,75**		**17,5**		**15,5**	

Level of Implementation Complexity	Subject of Monitoring (Who?)	Object of Monitoring (What?)
1st	Mobile	Mobile
2nd	Mobile	Static
3rd	Static	Mobile
4th	Static	Static


Energy
Saving
Information
Processing
Availability
Research object

Part 2

Wild Animal Monitoring Using Wireless Sensor Networks

Information aggregation about wild animals habits in their natural environment

Image copyright: rcvernors @ Flicker

Main challenges


Correct detection of animal activity
Image from: oregonlive.com

Power efficient design

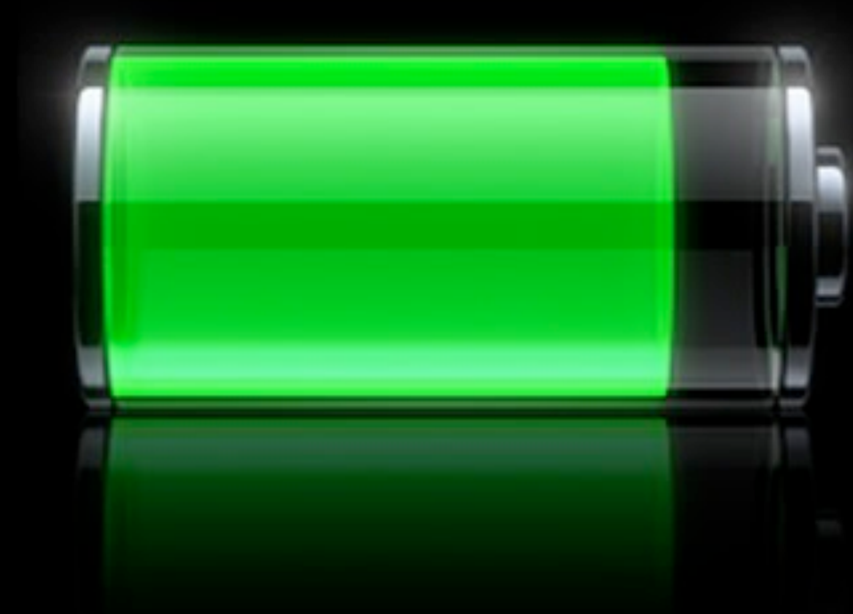


Image from: appadvice.com

KEEP IT SIMPLE.

Researchers without WSN expertise should be able to use it.

LynxNet project


Image from: craigcentral.com
Eurasian lynx
(Lynx lynx)

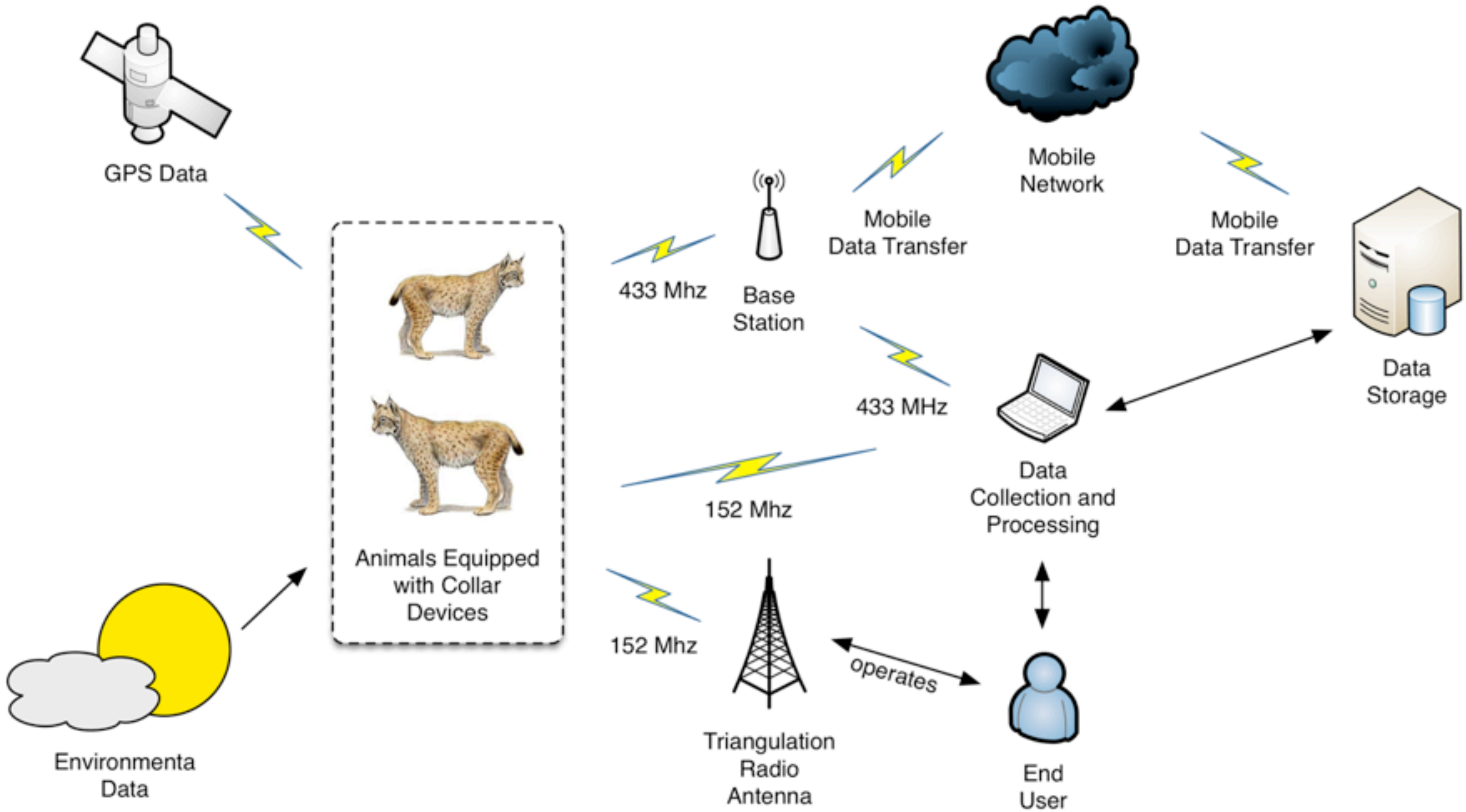
Existing solution

FOLLOWIT
Keep track of everything.

http://wildlife.followit.se/

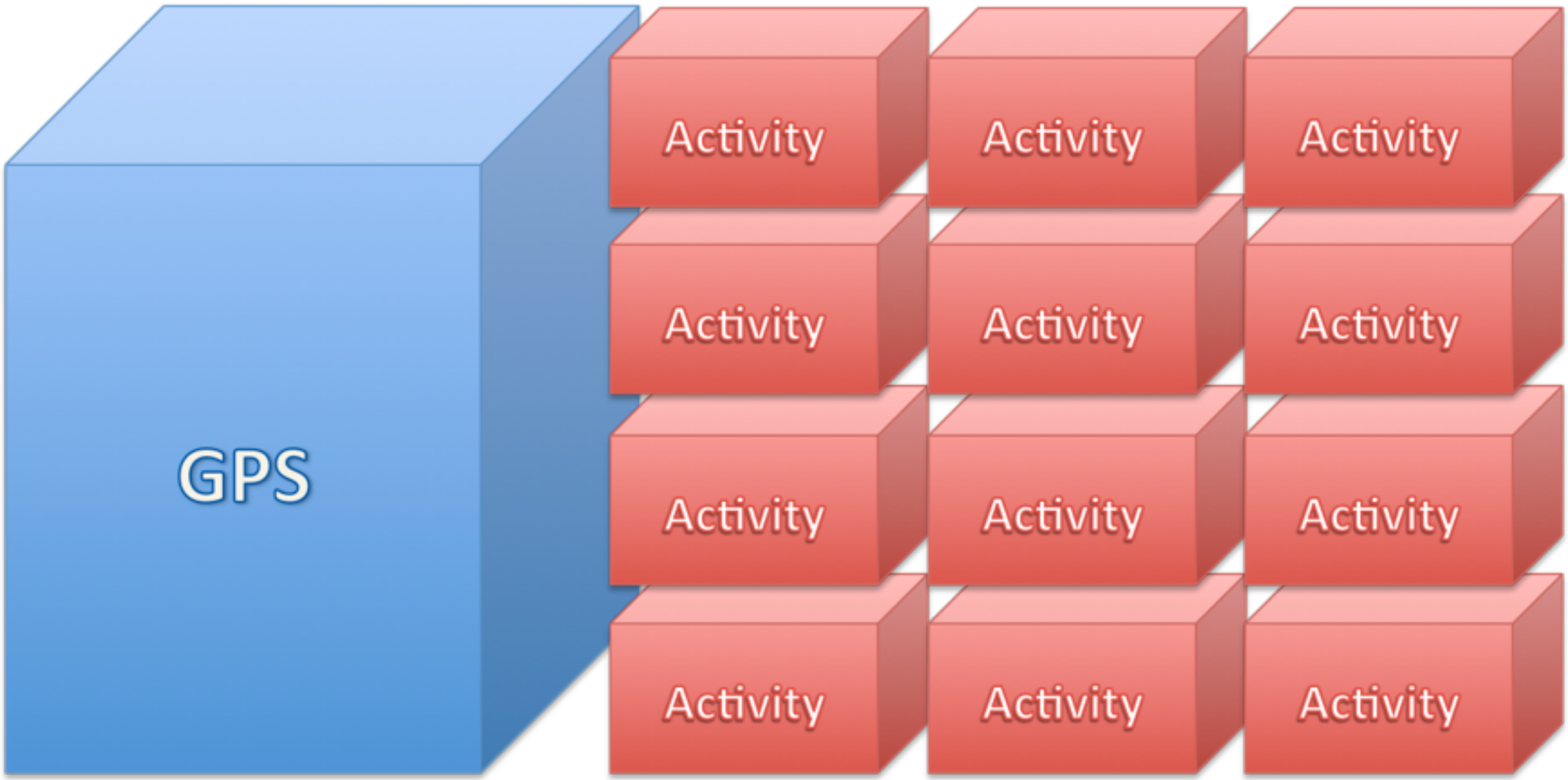
Approach

System architecture



- Runs on MansOS embedded operating system
- Periodically acquires data from sensors and GPS
- Detects animal activity based on data from sensors
- Saves all acquired data on SD card
- Transmits data if near base station
- Saves battery life by seizing data acquisition when its too cold
- Uses VHF band as backup communication channel

1h = 13 data packages



GPS data

Field	Size (bytes)
Timestamp	4
Unit ID	1
GPS latitude	4
GPS longitude	4
GPS information	1
Temperature	2
Humidity	2
Light	2
Total size	**20**

Timestamp size: log2(60) + log2(60) + log2(24) + log2(31) + log2(12) + 1 = 6+6+5+5+4+1 = 27 bits = 4 bytes

Activity data

1st packet

Field	Size (bytes)
Timestamp	4
Unit ID	1
Series ID	3
Series size	2
Total size	**10**

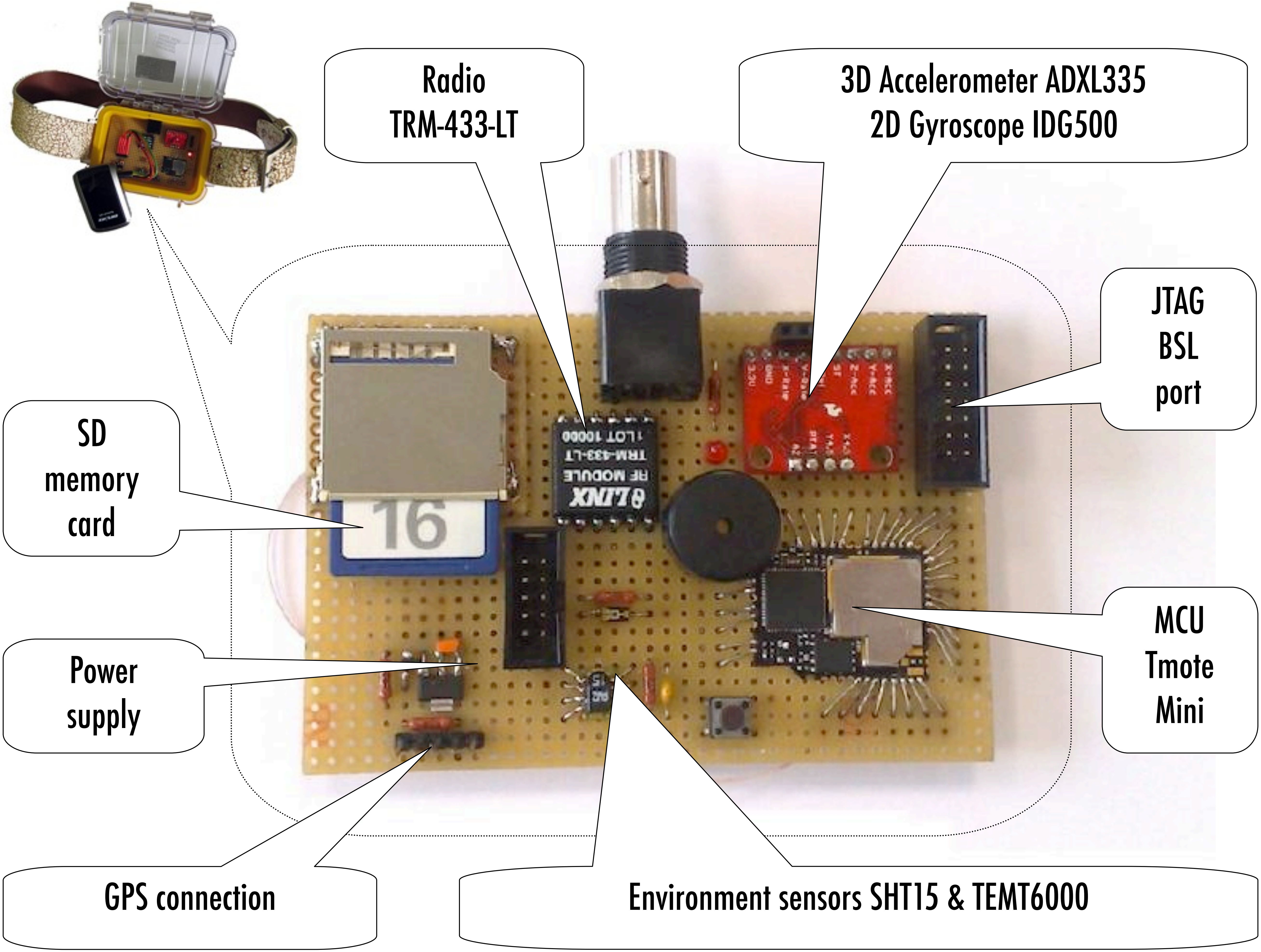
Timestamp size: log2(60) + log2(60) + log2(24) + log2(31) + log2(12) + 1 = 6+6+5+5+4+1 = 27 bits = 4 bytes

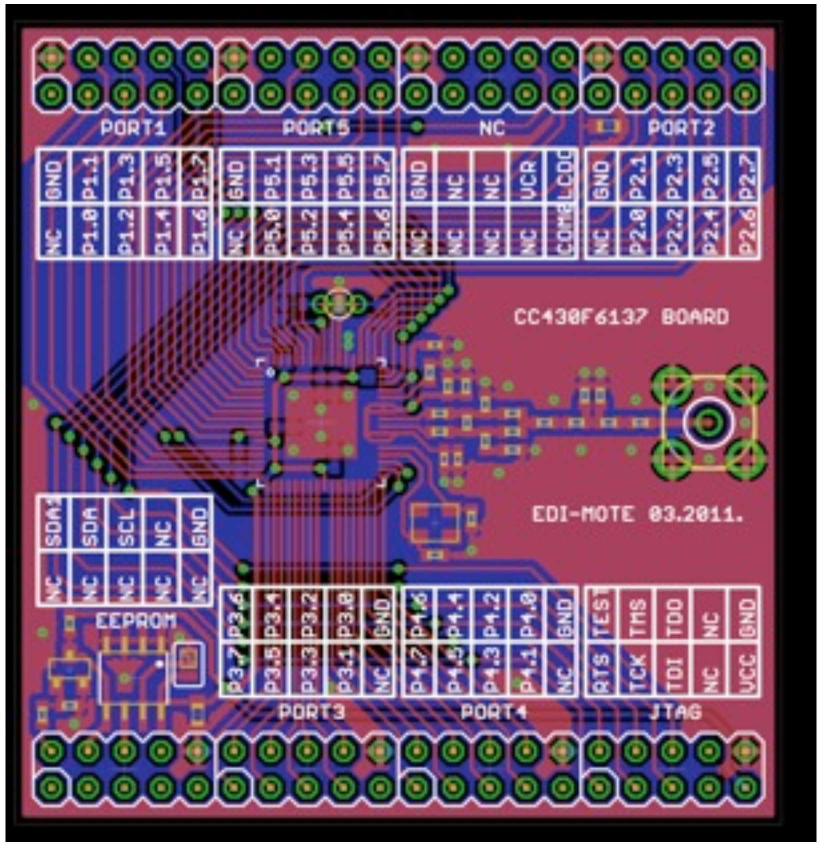
Activity data

Consequential packets

Field	Size (bytes)
Series ID	3
Unit ID	1
Packet ID	2
Average accelerometer X axis	2
Average accelerometer Y axis	2
Average accelerometer Z axis	2
Average gyroscope X axis	2
Average gyroscope Y axis	2
Average gyroscope Z axis	2
Average magnetometer X axis	2
Average magnetometer Y axis	2
Average magnetometer Z axis	2
Total size	**24**

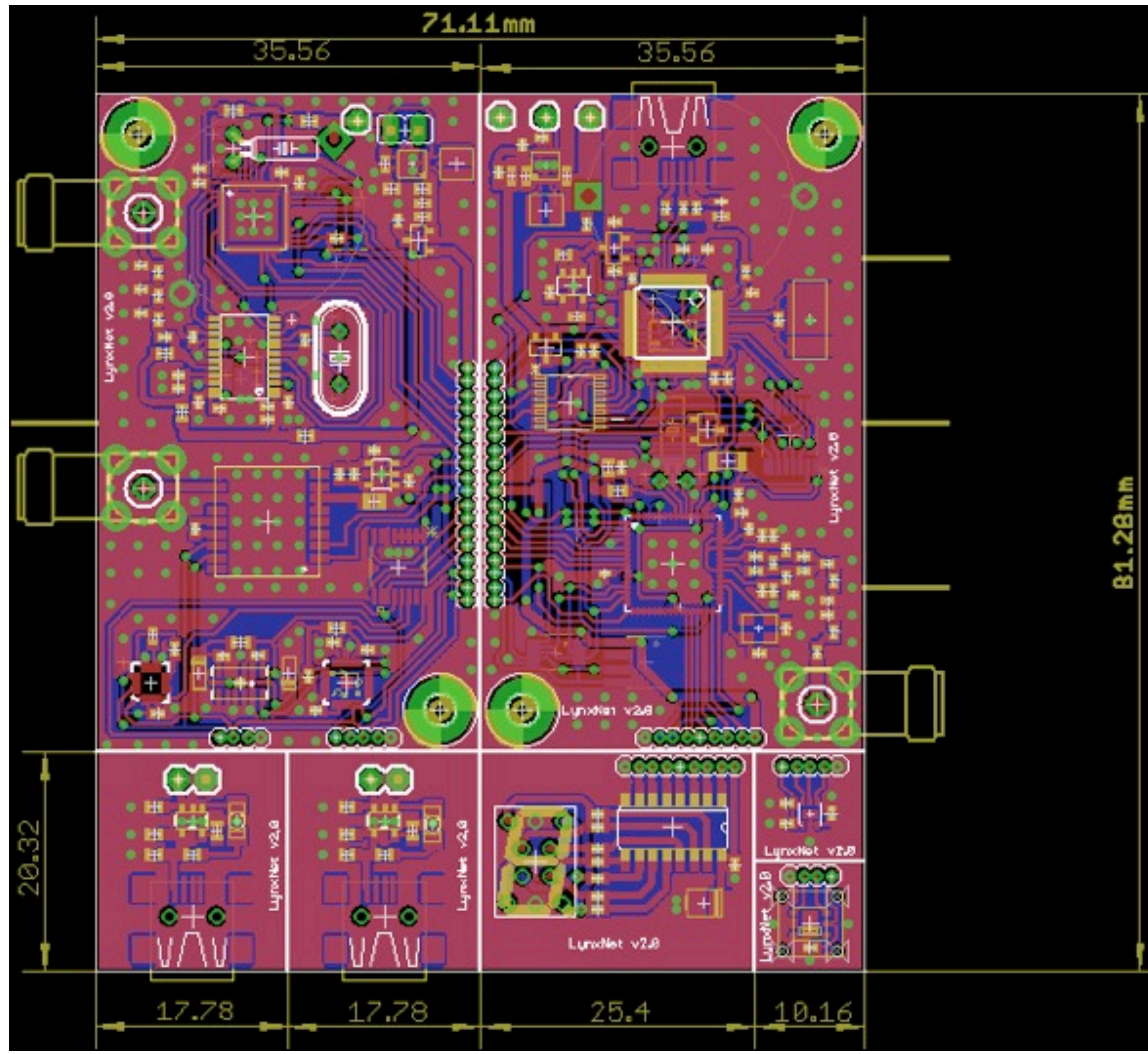
Prototypes

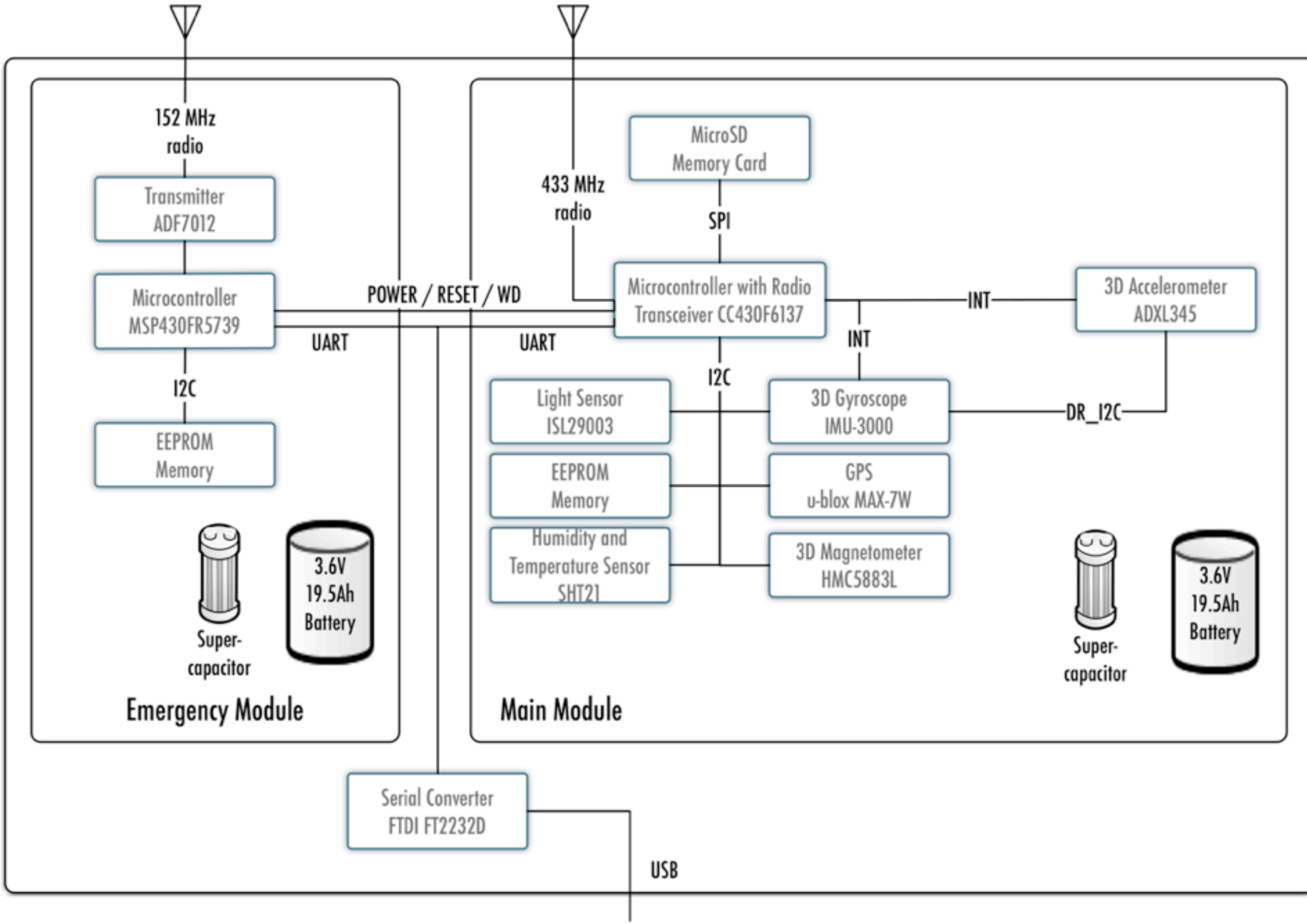

Radio
TRM-433-LT
3D Accelerometer ADXL335
2D Gyroscope IDG500
JTAG
BSL
port
SD
memory
card
MCU
Tmote
Mini
Power
supply
GPS connection
Environment sensors SHT15 & TEMT6000
16
RF MODULE
TRM-433-LT
LINX



Prototype 1.5

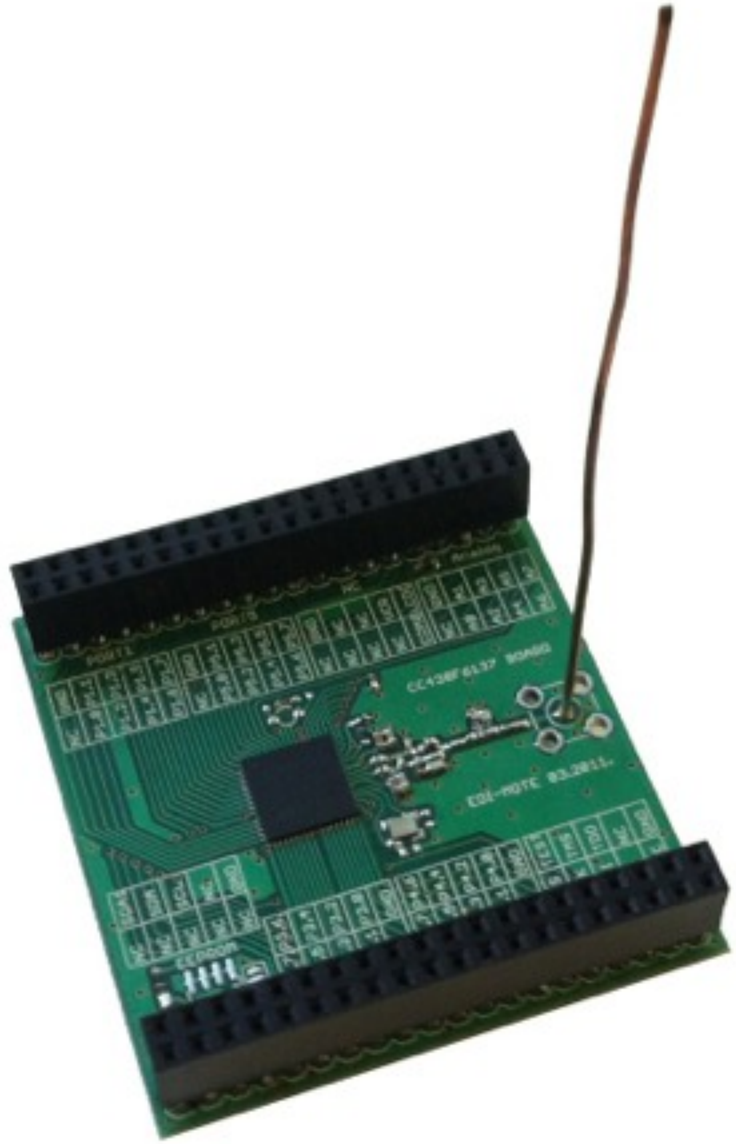
Prototype 2.0




152 MHz
radio
Transmitter
ADF7012
Microcontroller
MSP430FR5739
I2C
EEPROM
Memory
3.6V
19.5Ah
Battery
Super-
capacitor
Emergency Module
POWER / RESET / WD
UART
UART
433 MHz
radio
MicroSD
Memory Card
SPI
Microcontroller with Radio
Transceiver CC430F6137
INT
3D Accelerometer
ADXL345
INT
I2C
Light Sensor
ISL29003
3D Gyroscope
IMU-3000
DR_I2C
EEPROM
Memory
GPS
u-blox MAX-7W
Humidity and
Temperature Sensor
SHT21
3D Magnetometer
HMC5883L
Super-
capacitor
3.6V
19.5Ah
Battery
Main Module
Serial Converter
FTDI FT2232D
USB

Lifespan of LynxNet prototypes

	1st prototype	1.5th prototype	2nd prototype
System's voltage:	3.3 V	3.0 V	3.0 V
Energy source:	1300 mAh @ 3.6 V	6800 mAh @ 3.75 V	19000 mAh @ 3.6 V
Operation	mA	mA	mA
MCU sleeps	0.058	0.116	0.113
MCU works	0.069	0.072	0.145
GPS	1.050	0.485	0.375
Activity sensors	0.026	0.026	0.220
Environment sensors	0.380	0.222	0.375
Radio RX	0.010	0.007	0.007
Radio TX @ 433 MHz	0.497 @ 9.77kbaud	0.188 @ 38.4kbaud	1.873 @ 38.4kbaud
SD card	0.058	0.057	0.067
Total per hour:	**2.175 mA**	**1.183 mA**	**3.201 mA**
Total hours:	**594**	**5443**	**5611**
Information volume:	**605 kB**	**7.9 MB**	**83.7 MB**



EDImote module
as base station
transceiver

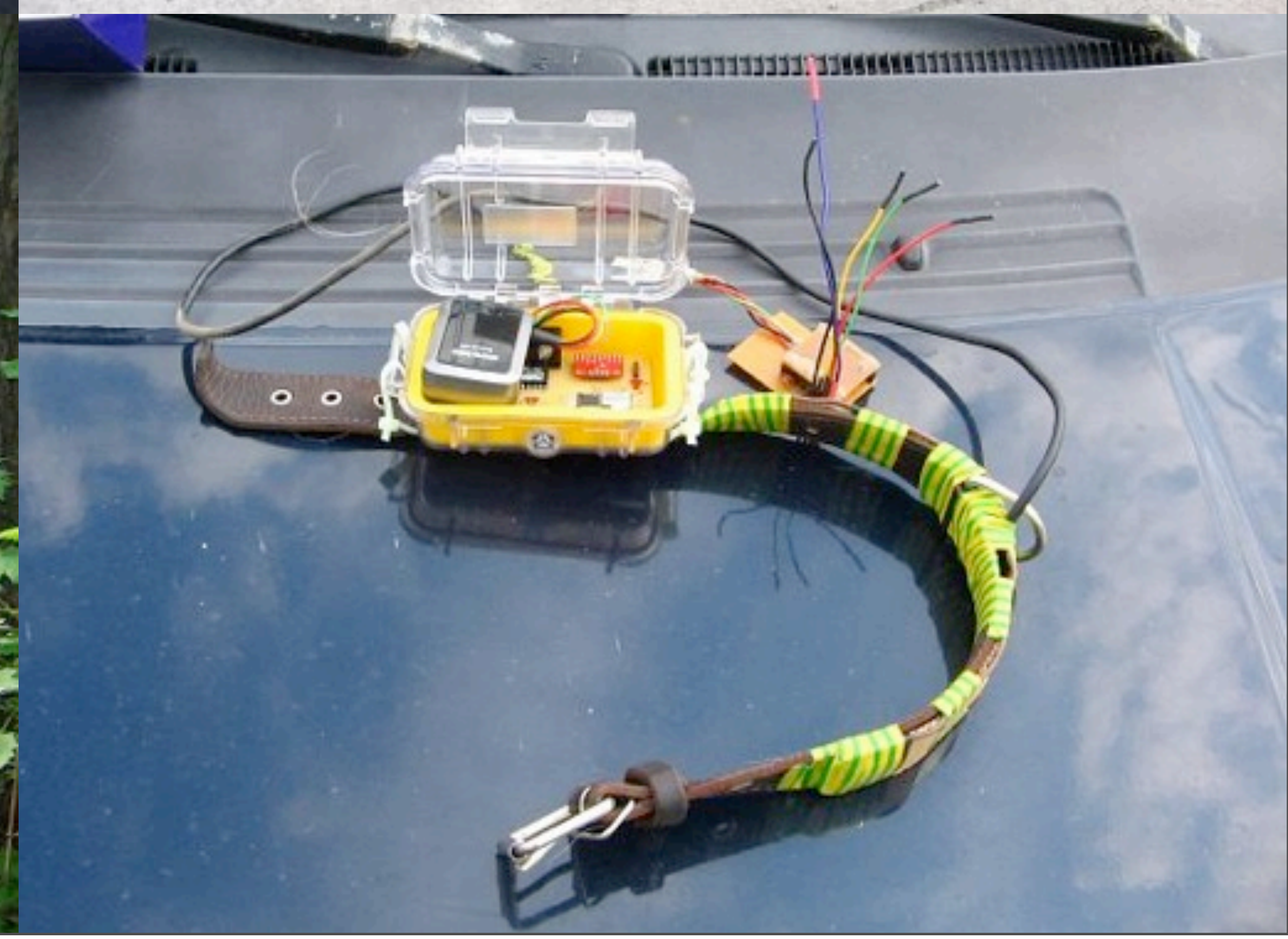
RaspberryPi
as base station
controller

Tests in wild

Radio tests @ Rumbula airfield

Radio tests @ Šampēteris forest

Images from: personal archive



Part 3

Heterogeneous Tool Kit for Real-Time Edutainment

ENTERTAINMENT
as well as
EDUCATION

Main challenges

Power efficient design of embedded device for long-term usage

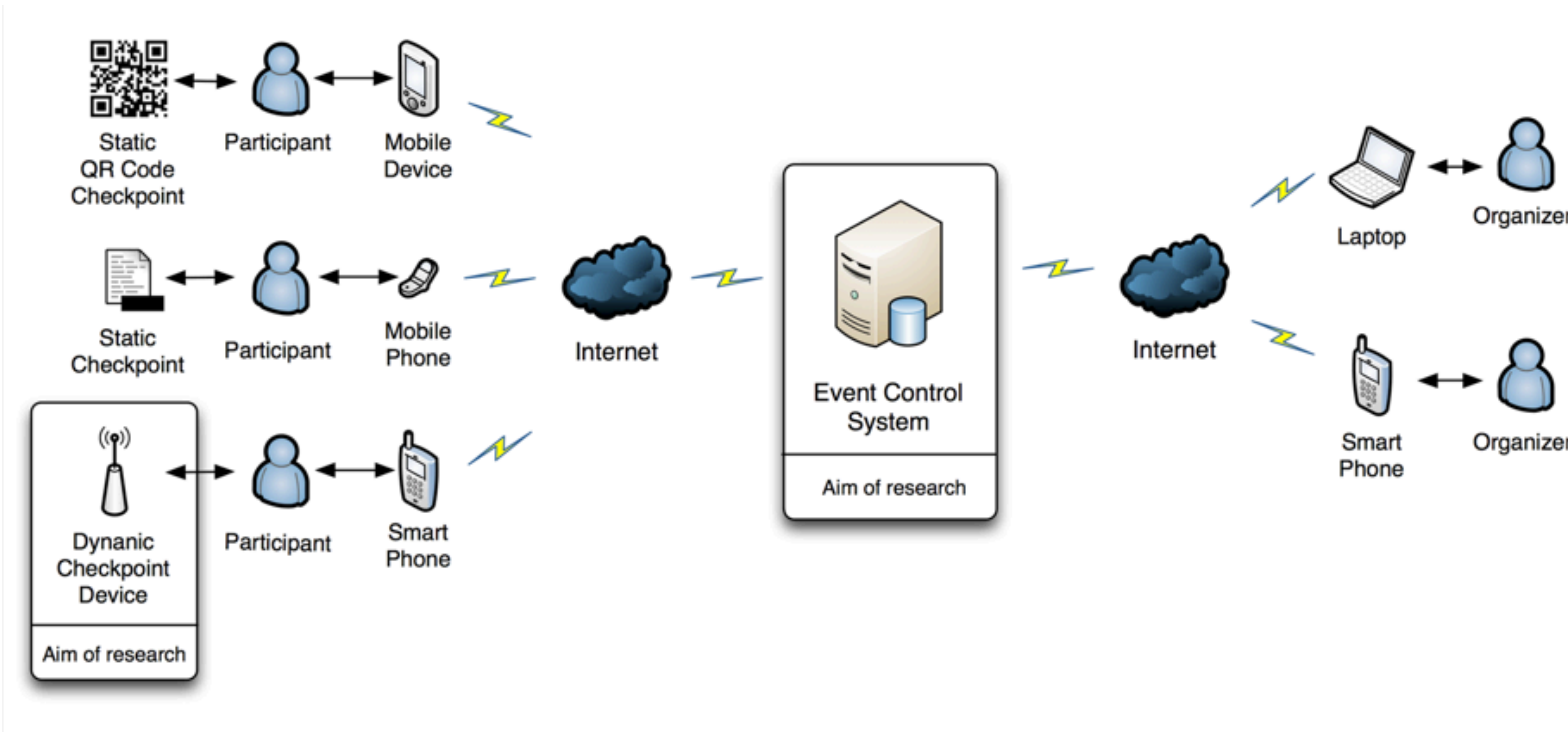
Image from: appadvice.com

KEEP IT SIMPLE.

People should be able to use the resulting technology
without reading huge manual.

Approach

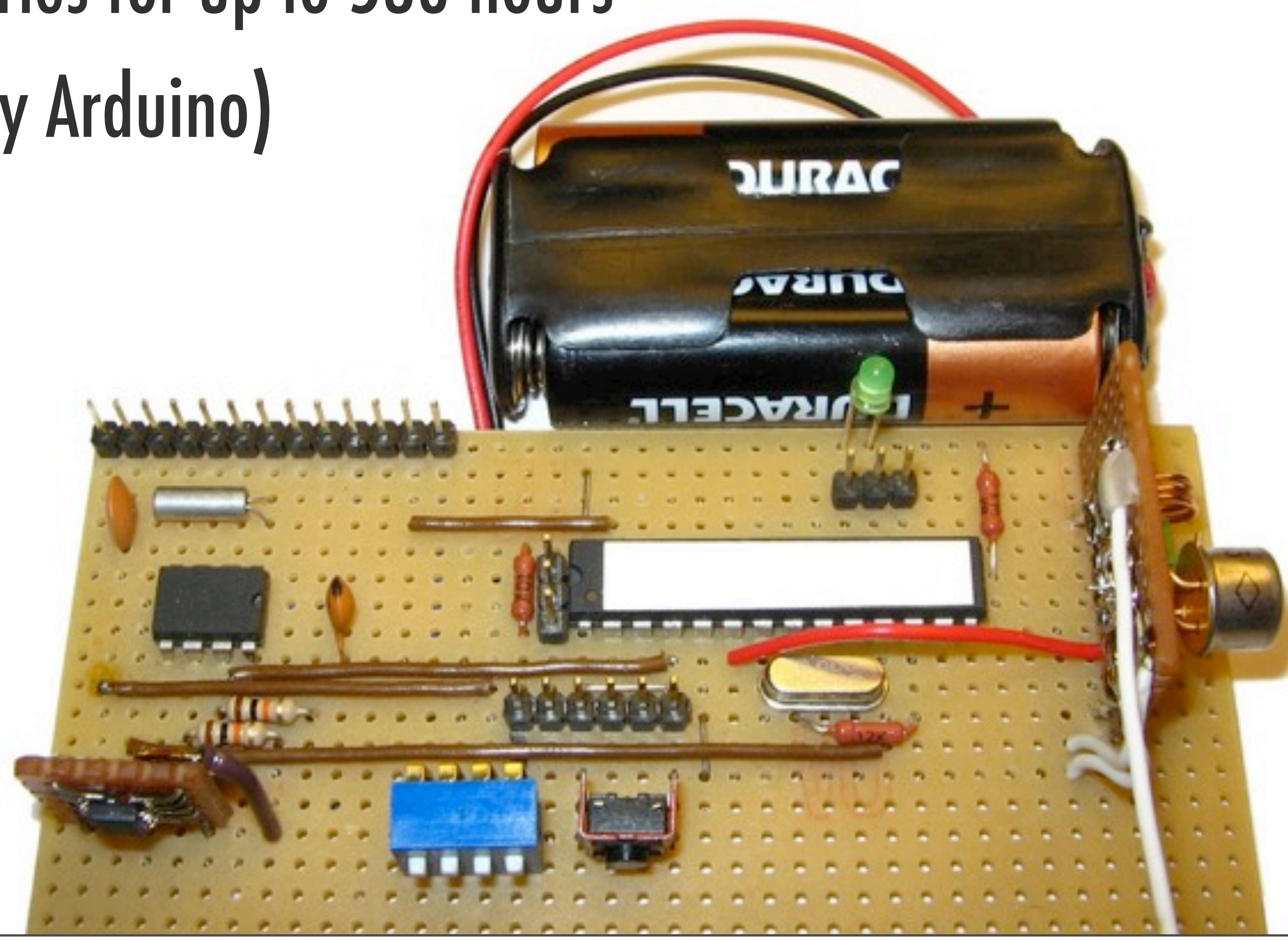
System architecture



Dynamic Checkpoint Device

Embedded device consists of following components:

- Atmel Atmega 328p MCU @ 8MHz
- NXP PCF8593P RTC chip to control timing of events
- Atmel AT24C64C 64KB EEPROM chip for data storage
- Transistor based FM SRD transmitter driven by micro controller
- Powers from 2 AA type batteries for up to 536 hours
- MansOS as firmware (initially Arduino)



Autonomous operation

Checkpoint code length, digits	Code transmission, sec	Consumption per hour, mWh	Autonomous operation, h (days)
4	18	10.74	536 (22)
6	27	11.87	485 (20)
8	36	12.53	460 (19)

Event Control System

- Lightweight web based application
- Works in standard PC Internet browser or any HTML-enabled smartphone
- Customizable and configurable for event requirements
- Allows full event management

Experiments

Toolkit has been tested in 23 various events:

- 1 event with dynamic checkpoint device and static checkpoints
- 3 events with only QR codes as static checkpoints
- 5 events where participants GPS tracks were evaluated
- 2 events where participants should locate organizers in event's territory using GPS coordinates transmitted by organizers and also find static checkpoints
- 12 events with just static checkpoints and other types of tasks, i.e., timed tests or task evaluated by referee

Part 4

Web Services for Low-Power Wireless Sensor Networks

(WSN-SOA)

Easy information exchange with wireless sensor network

Image from: lenscases.co.uk

Main challenges

Limited resources vs. functionality

Image from: angelairvin.com

KEEP IT SIMPLE.

"Most consumers really, really, really don't want to be integrators,"
Bill Brown, GM of Motorola Mobility at Mobilize 2012

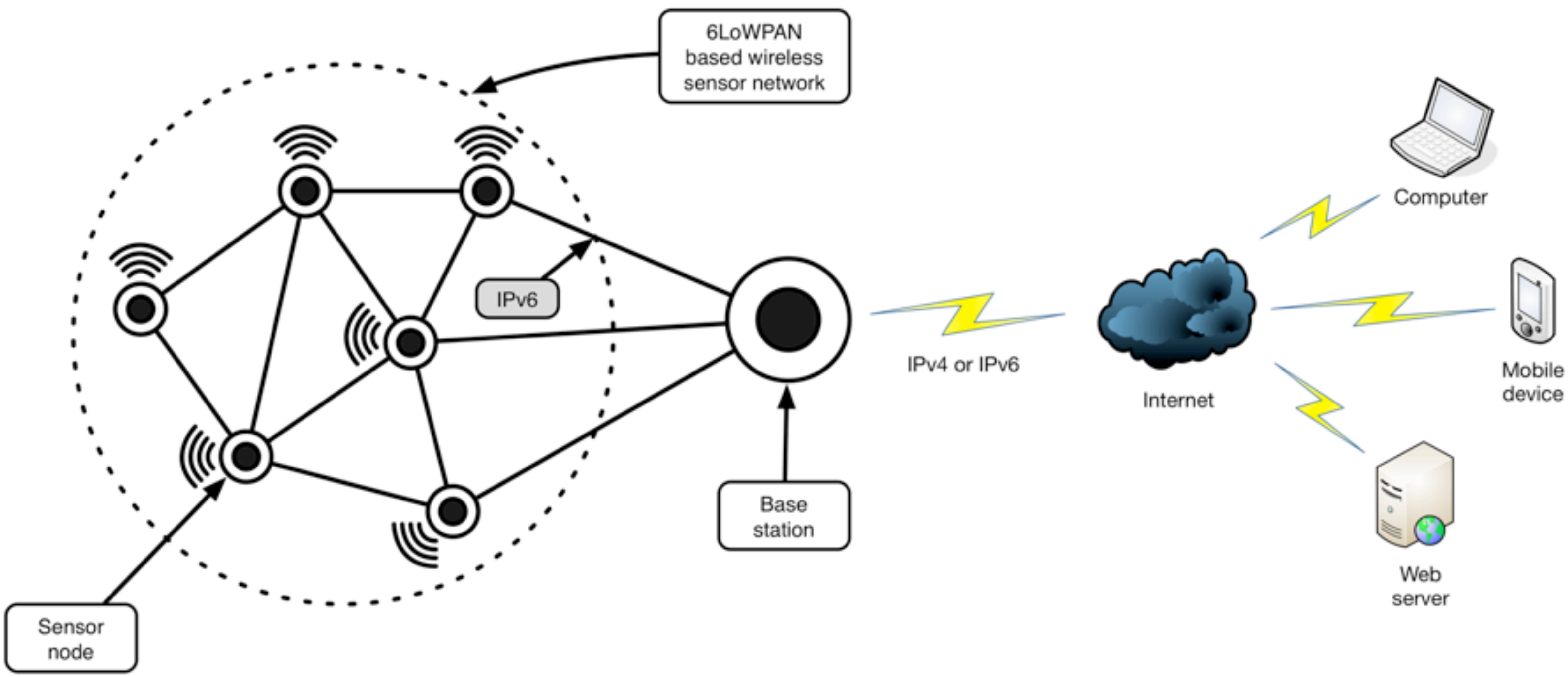
Approach

RESTful Architecture Over HTTP and DTN for Low Power Consumption Wireless Sensor Networks

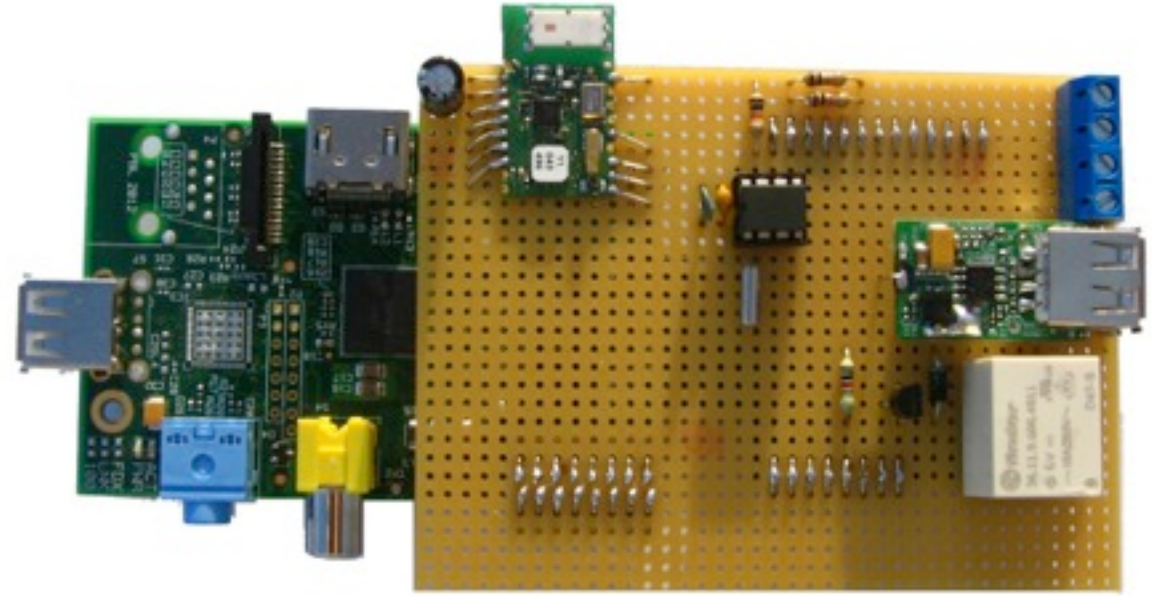
Image from: itswisp.co.uk

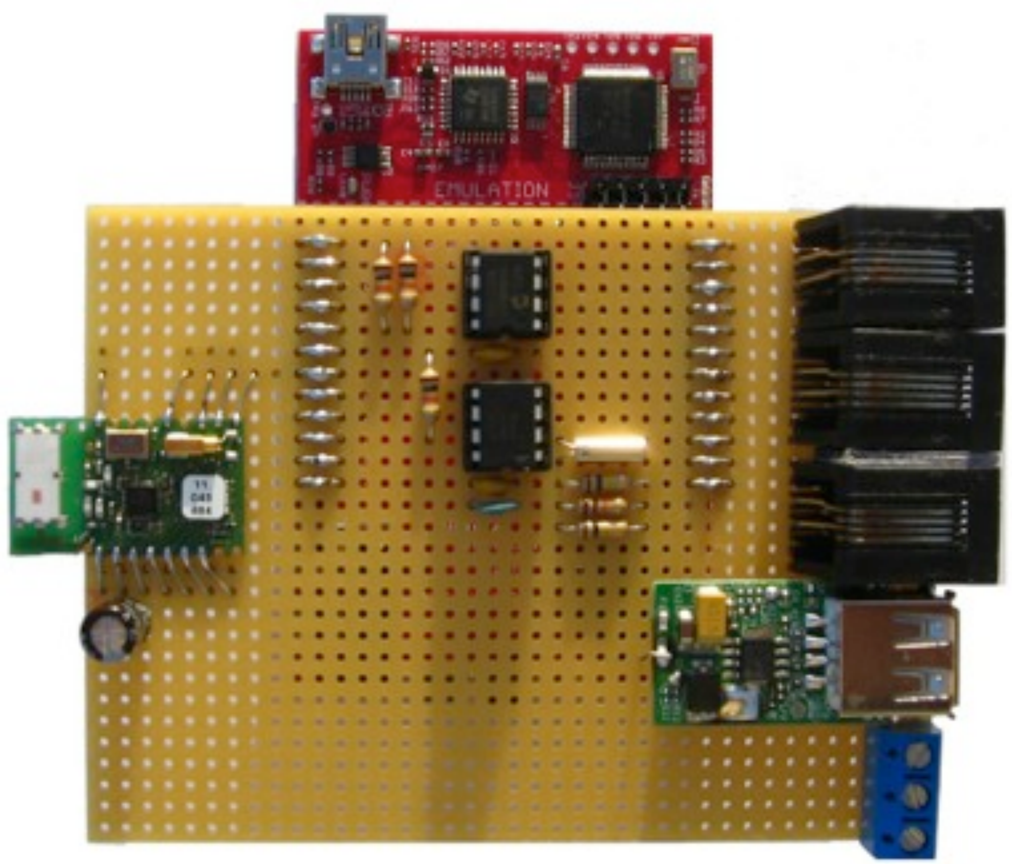
- UDP based embedded web server
- Runs over 6LowPAN (IPv6 for WSN)
- Session based, store-and-forward type protocol
- Data transmission using packets
- Packet prioritization and encryption

System architecture




FUJIFILM
4GB




EMULATION

Conclusion

Main contribution during research:

- General method for creating embedded sensor device was developed
- The LynxNet system was created for wild animal monitoring
- The system and tools were developed for the management of dynamic events with gamification elements
- The service-oriented architecture WSN-SOA suitable for wireless sensor networks was created

Minor contribution during research:

- An experimental approach of road surface quality monitoring was created
- An experimental approach for autonomous driving of a car within cooperative driving scenario was developed
- An environment conditions monitoring system for a fruit garden was developed

Track record

- In total 9 papers related to subject of Thesis, 4 of them SCOPUS indexed
- Attended and presented Thesis research results in 14 workshops or conferences
- Made and presented 2 posters about Thesis research

Thank you!

Contact me – reinholds @ zviedris.lv