Networking the Garden from First Principles with a Custom, Low-Cost WSN Platform

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Introduction

- **No exploitation of existing commercial WSN solutions**
- Instead, creation of a multi-hop WSN from first principles
  - Design and implementation of low-cost/ low-power WSN nodes
  - In-house fabrication of low-cost humidity sensors
  - Implemetation of a low-power information routing protocol
- Plant microclimate monitoring in agricultural fields and flower gardens
- Irrigation scheduling for precision agriculture and water saving

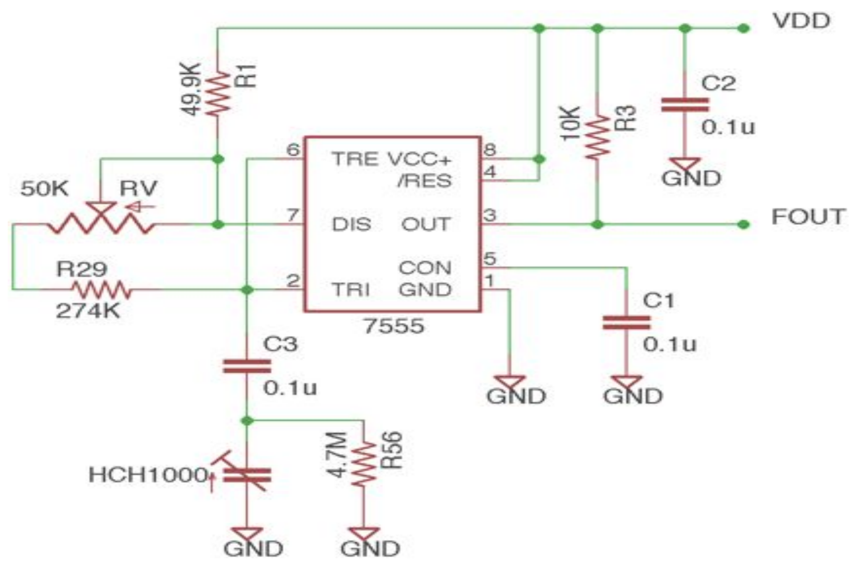
Design and Implementation of i-Cubes: Low-Cost/ Low-Power WSN Nodes

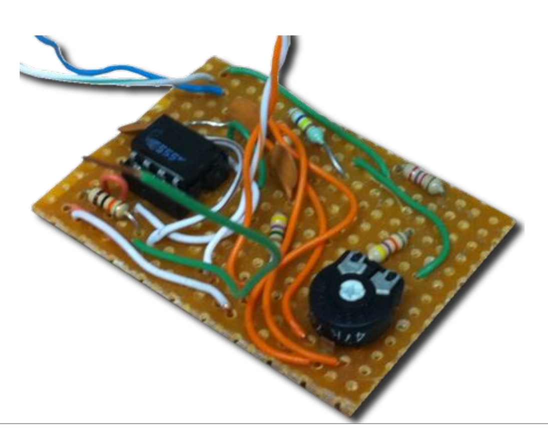
- Custom PCB Design and in-house node fabrication
- MCU: **Silabs C8051F320/1**
  - ADC/DAC units
  - UART, I2C, SPI, USB communication
  - Low-power operation modes for battery operating applications
  - Simple 8051 architecture
  - Well-witten manual, ideal for research and education/training purposes
- Radio Module: **Chipcon/TI CC2500**
  - 2.4GHz ISM Band
  - FSK/MSK/OOK modulation schemes
  - Programmable data-rate & output power

Total cost per node: €42

In-house Fabrication of low-cost Humidity Sensors

- Motivation: Need for cheap, precise humidity sensors for lage scale agricultural applications
- Capacitive sensor circuit using Honeywell HCH-1000
- Outputs voltage pulses of frequency inversely proporional to %RH
- Working range of 0-100%RH



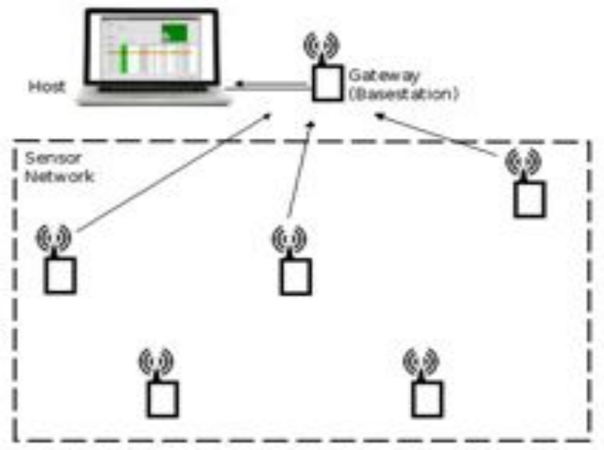


- Low-power 555 timer circuit variant
  - Max. current consumption of $300\mu A$
  - Min. operating voltage of $2V$

(Most 555 timers require $> 5V$ for operation, consuming $\sim 6mA$)

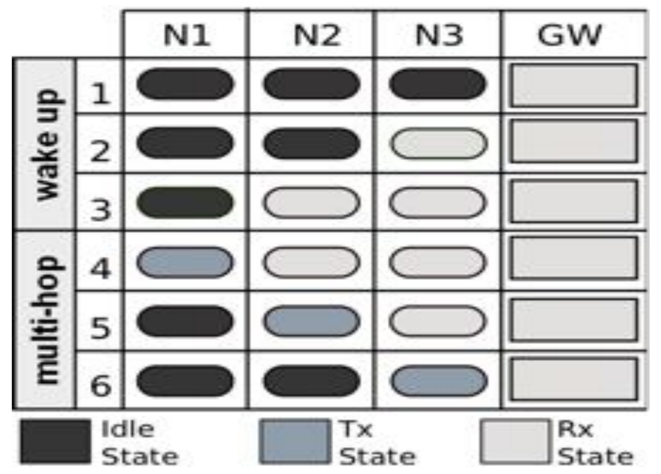
Total cost per sensor: €6 (ca. 4 times cheaper than commercial sensors)

Low-power Information Routing

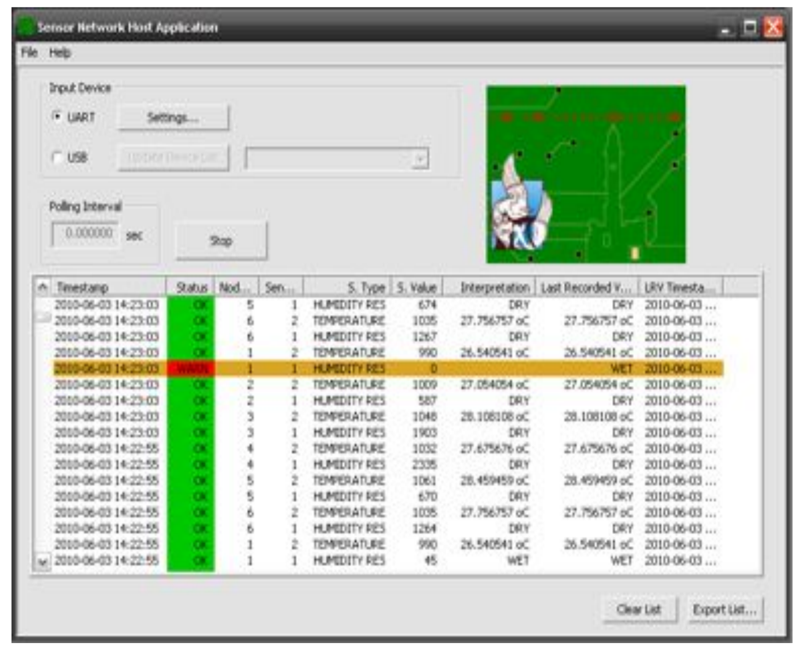


- FDMA: Network is divided into 2 chain groups, each one utilizing its own channel
- Sensor information multi-hops from the layer's first node towards the gateway (GW)
- Network's GW listens at its own, fixed frequency
- TDMA: Last chain nodes switch to the GW's channel and transmit the chain data

- After TX, each node's MCU is set in "No-Fetching Instruction" mode and Radio in "Idle" mode
- In each node, a hardware timer is used to get the MCU out of "idle" mode, before the chain's previous node transmits
- Finally, all information is forwarded to a PC, connected to the gateway



Outdoor Demonstration of a Multi-Hop WSN with iCubes

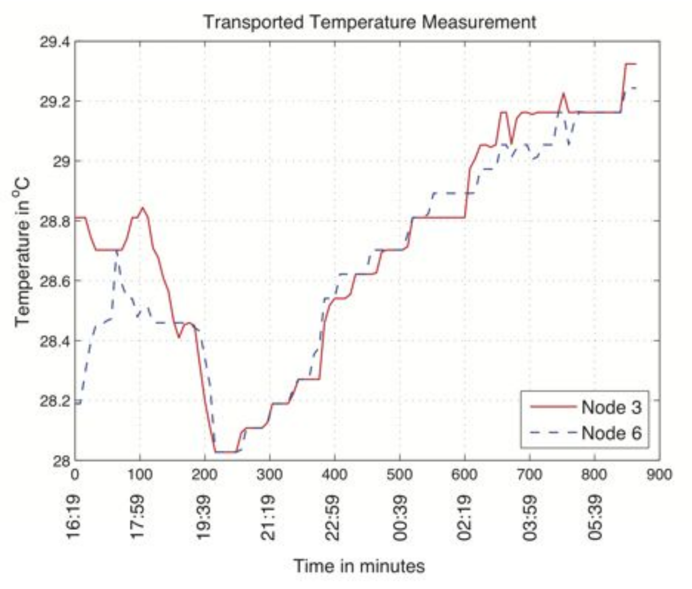


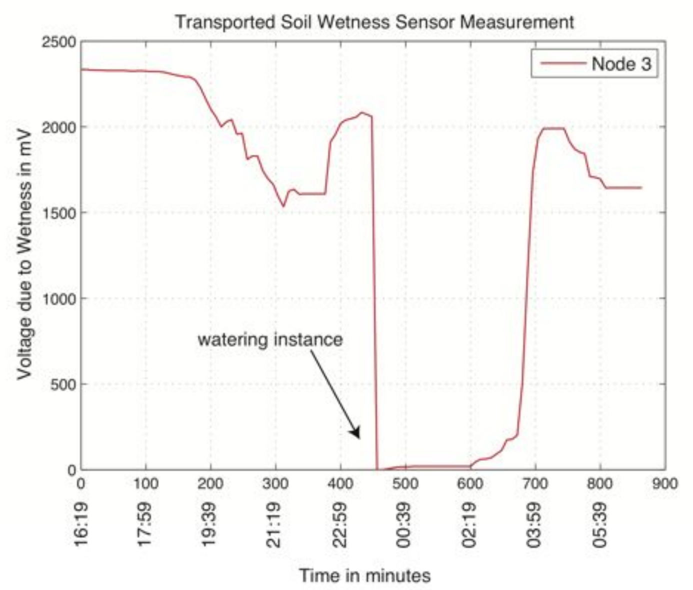
- Real-world iCubes WSN setup
- Microclimate sensing by means of the MCU's analog-to-digital converters:
  - Environmental temperature, using MCU's internal thermistor
  - Soil wetness, using *hand-made choke sensors for demo purposes*
- Collected data is presented in a graphical user interface, depicting measurement values, timestamps and useful interpretations for the values

Humidity Sensors Comparison Table

Manufacturer	TUC Telecom Lab	Honeywell	Honeywell	Sensirion
Model	Custom-with HCH1000	HIH3610	HIH4000	SHT1x
Range (*%RH*)	0-100	0-100	20-95	0-100
Supply Voltage (*V*)	2-18	4-5.8	4-5.8	5
Current Consumption (μA)	300	200	500	550
Cost (€)	6	30	24	19 - 22

Experimental Figures





WSN Nodes Comparison Table

Sensor Node	iCube	Isense	Micaz	BTnode
Developer	TUC Telecom Lab	Coalesenses	Crossbow	ETH
		MCU		
IC	Silabs C8051F321	Jennic JN5148	ATmega128L	ATmega128L
Speed (*MHz*)	1.5 - 24	4 - 32	up to 8	up to 8
Architecture	8-bit 8051	32-bit RISC	8-bit RISC	8-bit RISC
Flash/ROM (*KB*)	16	128	128 + 4(EEPROM)	128 + 4(EEPROM)
RAM (*KB*)	2.304	128	4	4
Consumption Active (*mA*)	0.41/MHz	0.28/MHz + 1.6	5 @ 4MHz	5 @ 4MHz
		Radio		
IC	CC2500	Jennic JN5148	CC2420	CC1000
Interface	SPI	(Single IC)	SPI	SPI
Max Data-rate (*Kb/s*)	500	250	250	76.8
Modulation	OOK, FSK, MSK	O-QPSK (802.15.4)	O-QPSK, MSK	FSK
Frequency Band (*GHz*)	2.4	2.4	2.4	0.868
RSSI/LQI	yes	yes	yes	yes
Consumption TX (*mA*)	10 @-22dBm, 21.2 @0dBm	15 @0.5dBm	8.5 @-25dBm, 17 @0dBm	8.6 @-20dBm, 16 @0dBm
Consumption RX (*mA*)	13.3@250Kb/s	17.5@250Kb/s	18.8@250Kb/s	11.8@76.8Kb/s
Consumption Idle (*mA*)	1.5	-	0.42	0.096
Max Transmit Power (*dBm*)	+1	+2.5	+0	+10
Max Sensitivity (*dBm*)	-104@2.4Kb/s	-95@250Kb/s	-95@250Kb/s	-110@0.6Kb/s
Sensitivity@250Kb/s (*dBm*)	-89	-95	-95	-96@76.8Kb/s (max rate)
		Node Capabilities		
ADC	14 channels	4 channels	8 channels	8 channels
Recommnended RTOS	Keil RTXtiny	custom	TinyOs	TinyOs
OTAP	yes (custom bootloader)	yes	yes	yes
RTOS-independent OTAP	yes (custom bootloader)	no	no	no
Batteries	2xAA	2xAA	2xAA	2xAA
		MCU+Radio Current		
CPU Sleep/Radio Off (μA)	0.1	0.1	15	15
CPU Idle/Radio Off (*mA*)	0.285	0.0012	4	4
CPU@8MHz/Radio Off (*mA*)	3.28	3.84	10	10
CPU@8MHz/Radio TX@250kbps (*mA*)	24.5 @0dBm	18.84 @0.5dBm	27 @0dBm	26 @0dBm
CPU@8MHz/Radio RX@250kbps (*mA*)	16.58	21.34	28.8	21.8

Conclusions

- Digital garden successfully built from first principles
- Low-cost implementation achieved due to own know-how
- Work can assist students and WSN researchers
- Encourage making custom applications without relying on commercial WSN products.