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
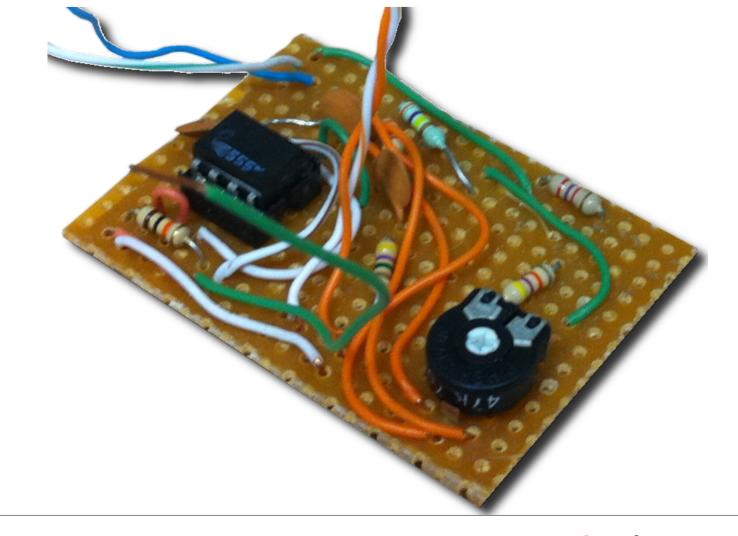▸ Irrigation scheduling for precision agriculture and water saving

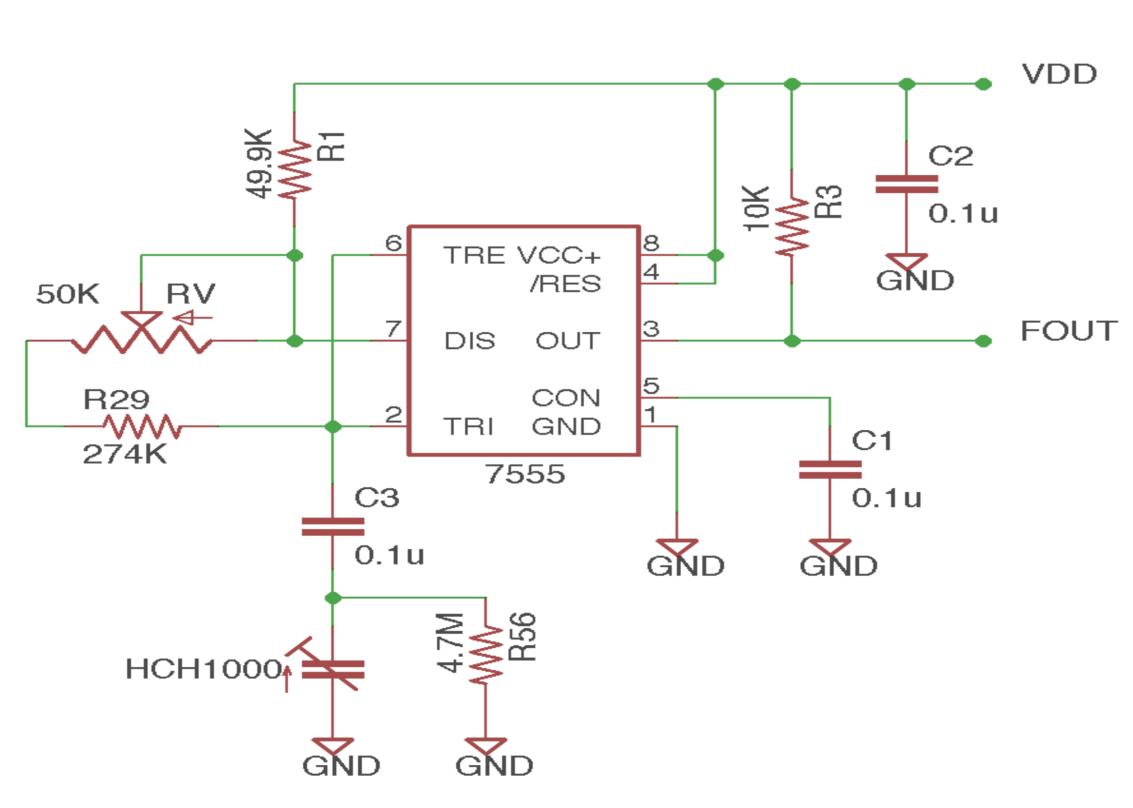## Design and Implementation of i-Cubes: Low-Cost/ Low-Power WSN Nodes

▸ 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
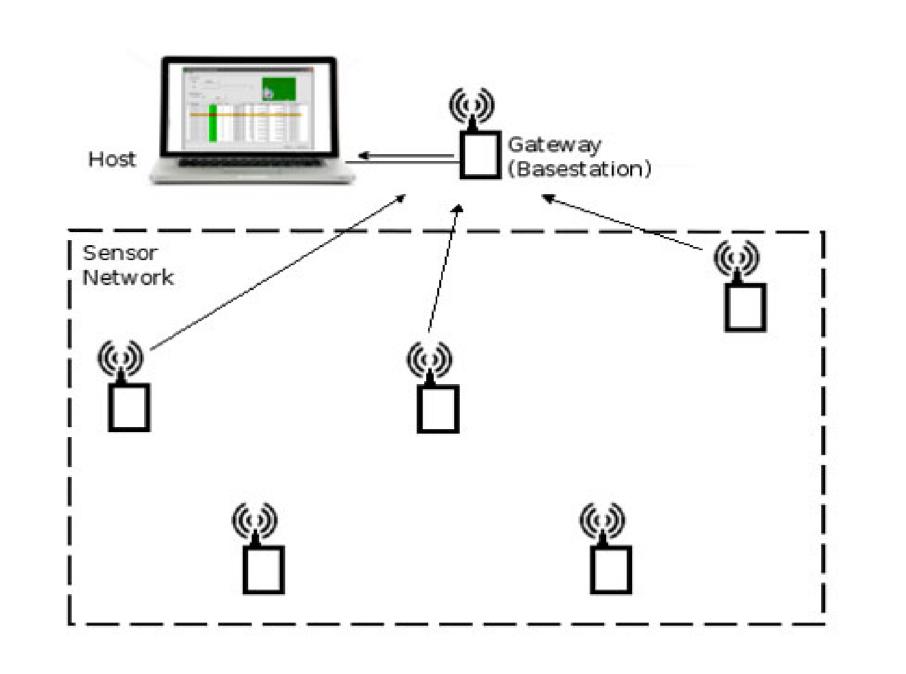▸ Working range of 0-100%RH

▸ 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 $\sim 6mA$)

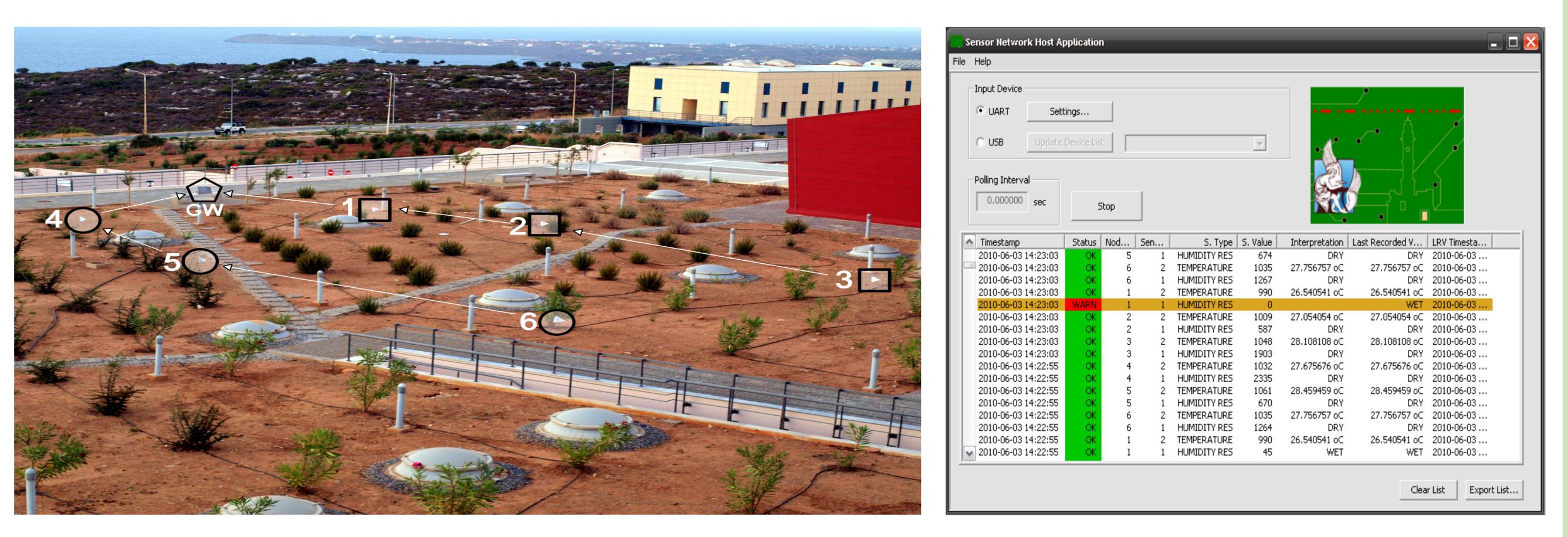**Total cost per sensor: €6** (ca. 4 times cheaper than commercial sensors)

Low-power Information Routing

▸ 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

▸ 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

		N1	N2	N3	GW
wake up	1	⬛	⬛	⬛	⬜
	2	⬛	⬛	⬛	⬜
	3	⬛	⬜	⬜	⬜
multi-hop	4	🟦	🟦	⬜	⬜
	5	⬜	🟦	🟦	⬜
	6	⬜	⬜	🟦	🟦

⬛ Idle State   🟦 Tx State   ⬜ Rx State

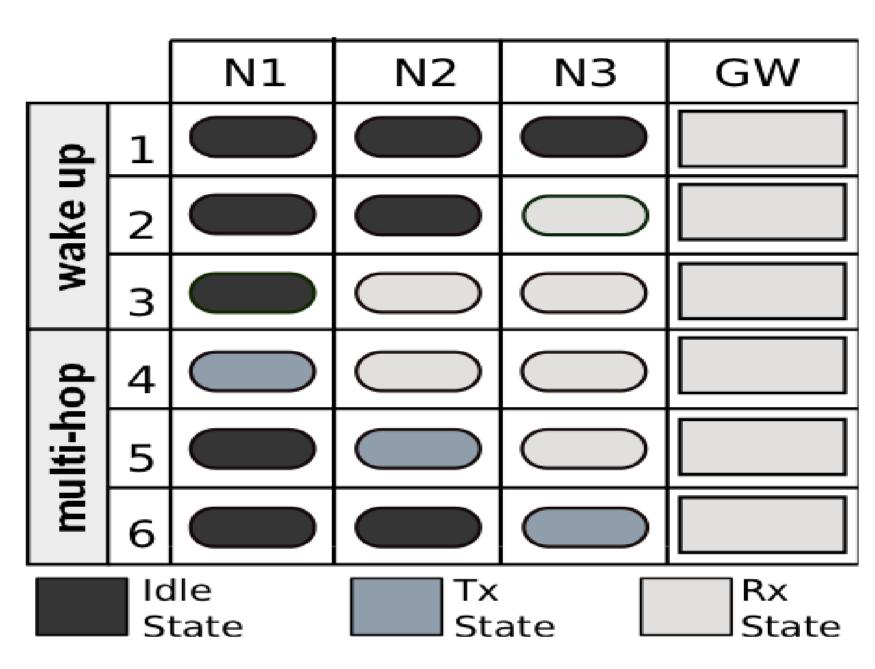## Outdoor Demonstration of a Multi-Hop WSN with iCubes

▸ 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
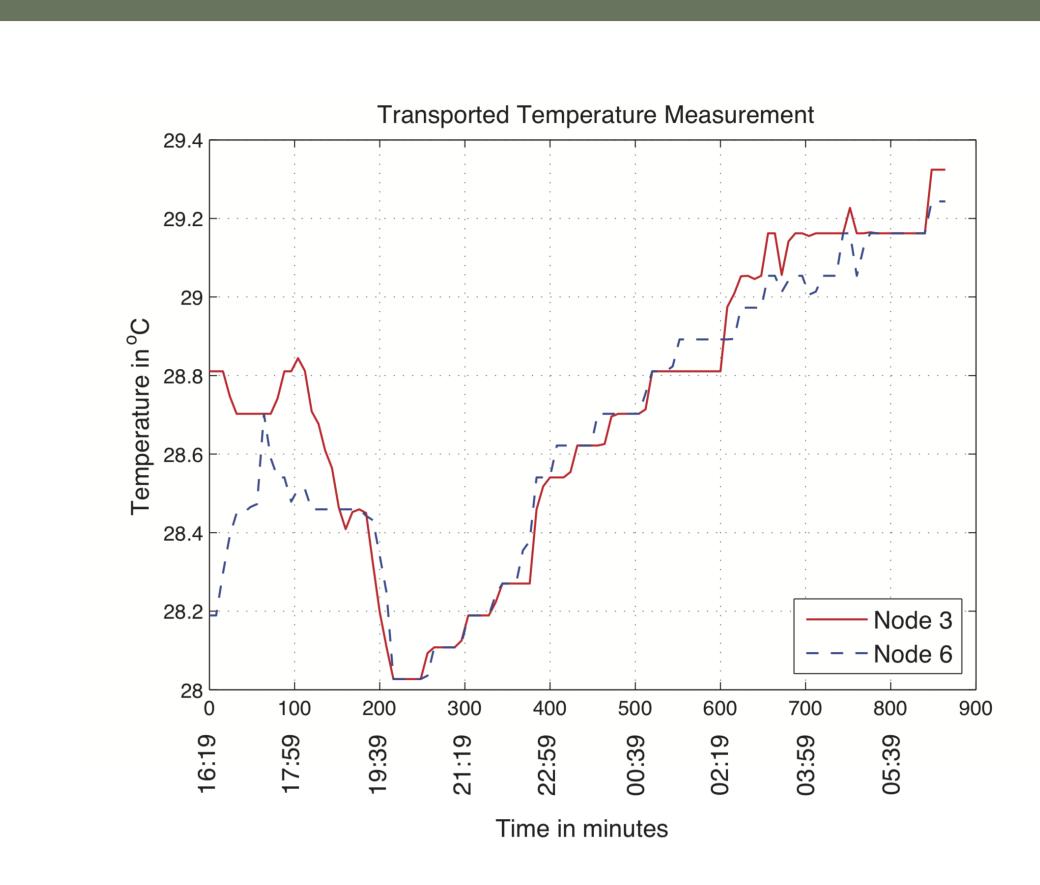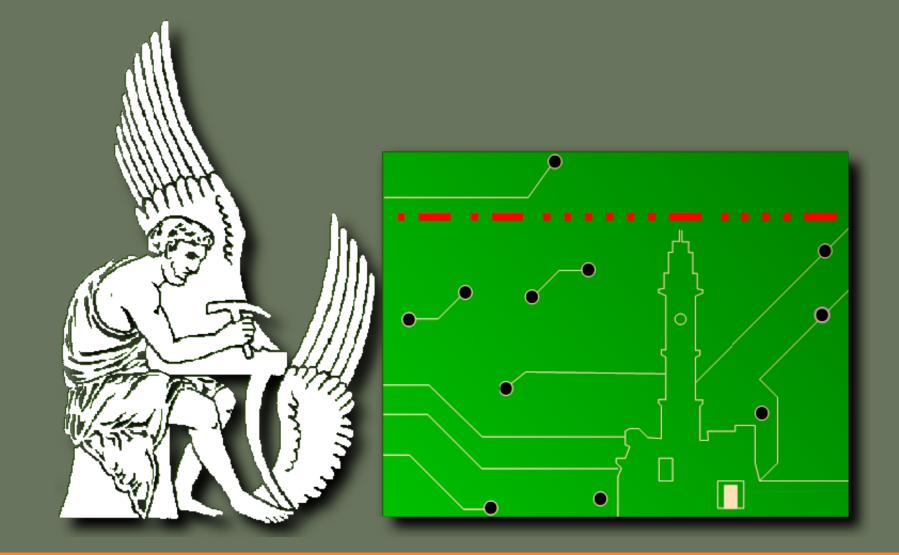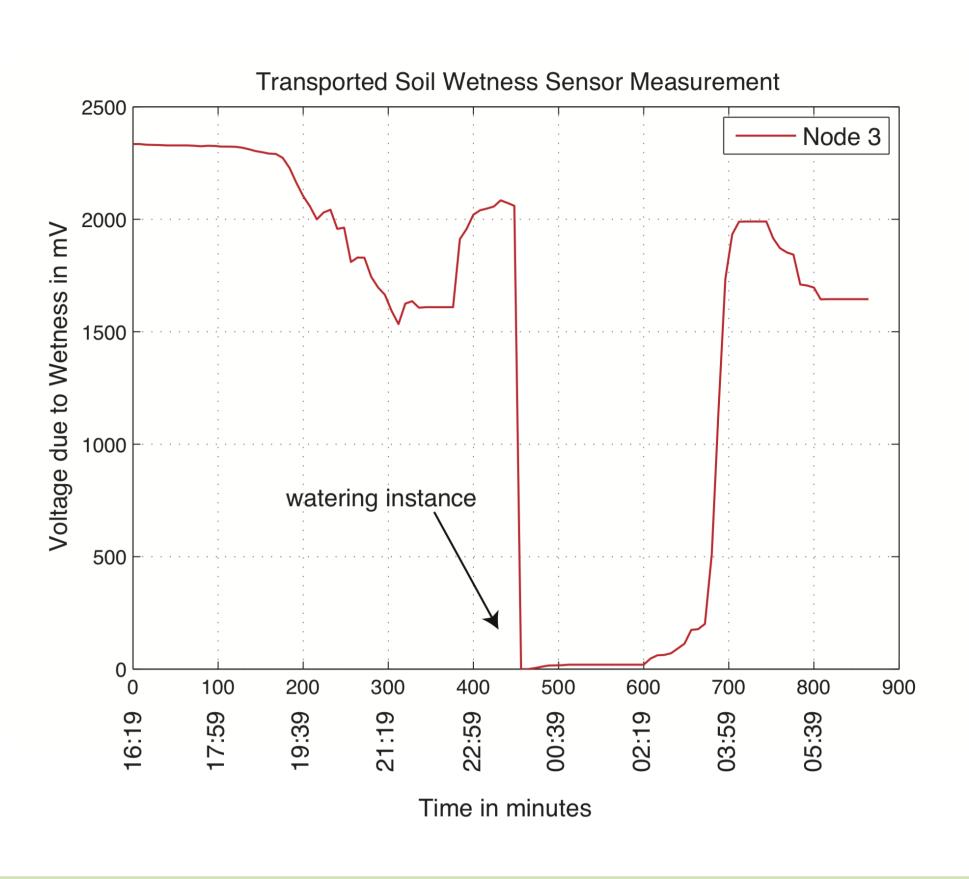
Humidity Sensors Comparison Table

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

Transported Temperature Measurement

Transported Soil Wetness Sensor Measurement

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.