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Mobile and Wireless Computing
CITS4419
Week 11: Underground WSNs (WUSNs)

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Motivation

- Sensor networks are situated in physical environments
- For some applications the nodes need to be hidden in the ground

Topics

- Why are underground WSNs needed
- What are the characteristics of WUSNs
- How do we implement WUSNs
- Case study: UWA farm network

- Reading: Wireless underground sensor networks: Research challenges, Ian F. Akyildiz and Erich P. Stuntebeck, Ad Hoc Networks 4 (2006) 669–686

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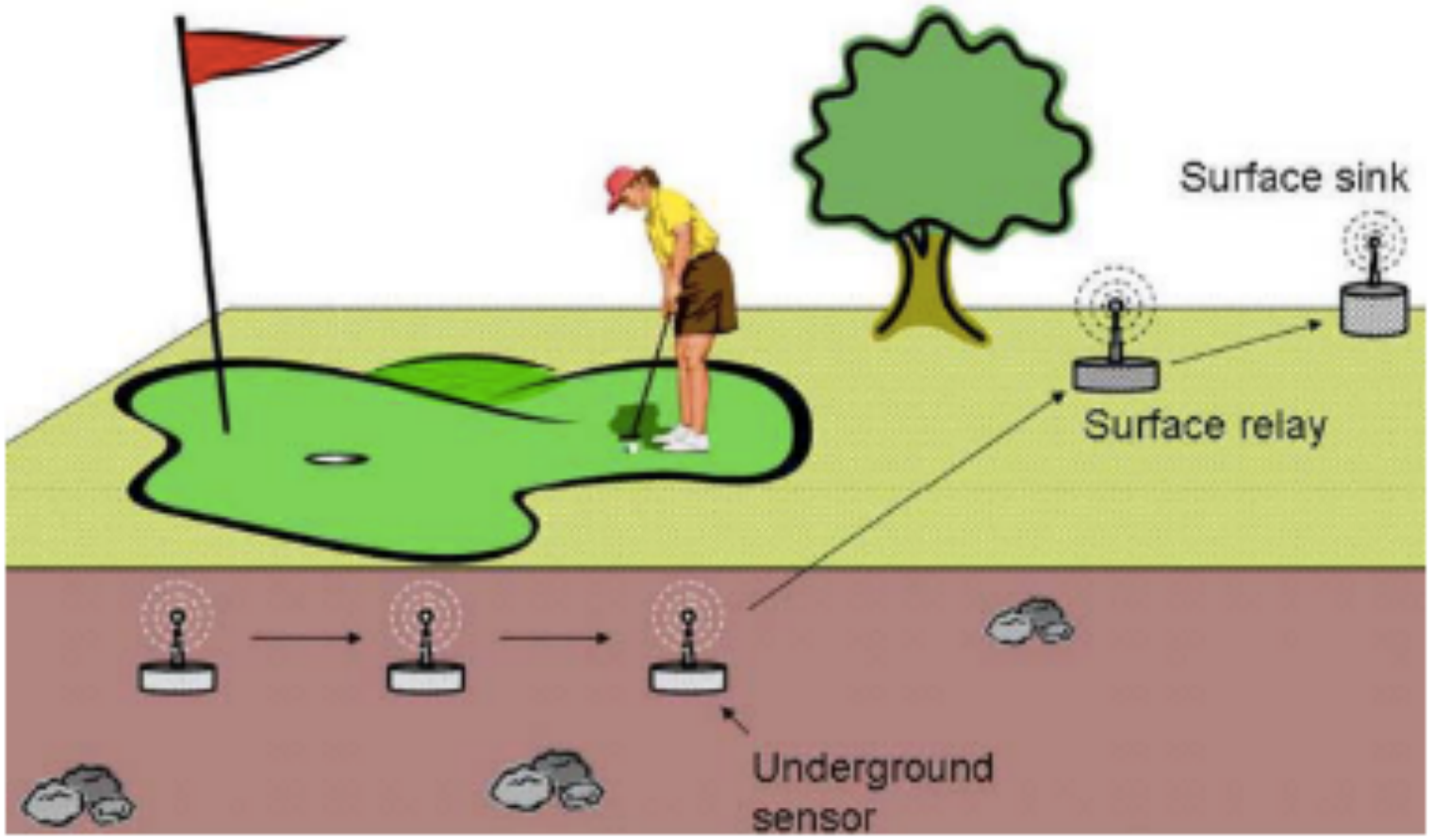
Applications for underground networks

Applications that require UG nodes

- Agriculture/Environment: monitoring soil conditions
- Irrigation applications (eg golf courses)
- Infrastructure monitoring: pipes, liquid storage tanks, building foundations etc
- Landslide and earthquake monitoring: buried seismometers
- Location beacons: UG sensors with known locations eg in roads for cars, navigation aid, emergency relief
- Border patrol and security monitoring: UG perimeter sensors to detect intruders

WUSN Application



Source: Akyildiz et al, Ad Hoc Networks 2006

WUSN characteristics

WUSN Organisation

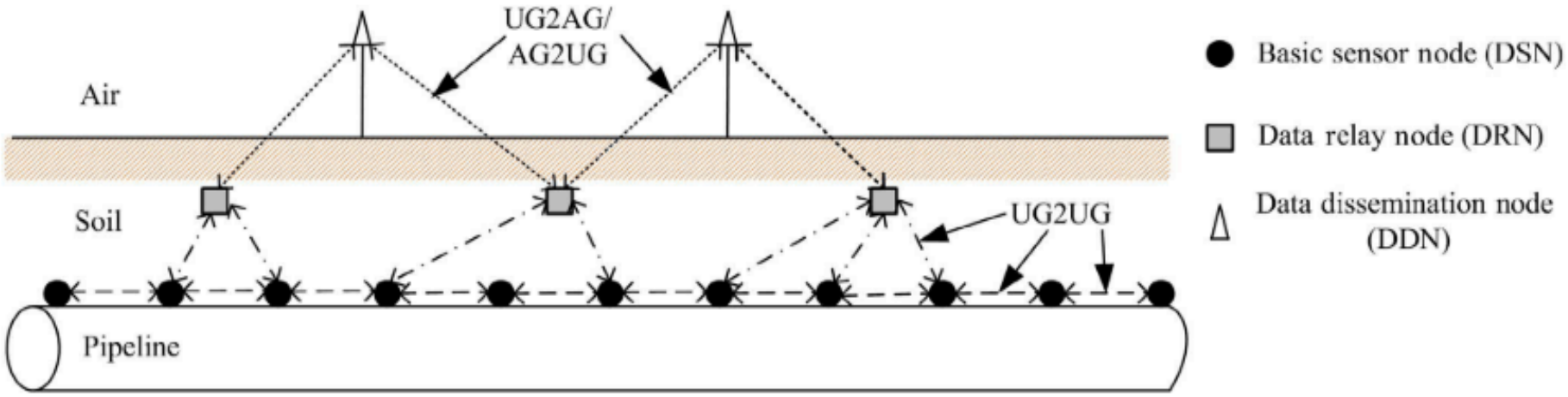


Fig. 1. WUSN for underground pipeline monitoring.

Source: Silva et al, Trans Industrial Informatics 2015

UWSN Challenges

- deployment
- power conservation
- topology design
- antenna design
- HW for environmental extremes
- protocol design

Communication Channels

- A comprehensive channel model for the underground does not yet exist
- **Extreme Path Loss** due to material absorption is a major concern
- **Reflection/refraction**
  - When the propagating EM wave reaches the ground–air interface, it will be partially reflected back into the ground and partially transmitted into the air, (and vice versa)
- **Multi-path fading** – also caused at the air-soil interface
- **Reduced propagation velocity** - in soil
- **Noise** – from power lines, lightening, electric motors, and some atmospheric noise

Link Quality

- UG-UG channel
  - stable, symmetric, but very short range
- UG-AG, AG-UG channel
  - asymmetric and exhibit similar temporal properties to over-the-air communication channels

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WUSN Solutions

UG-UG links

- stability of the channel can be exploited for fast link quality estimation, where RSS-based link quality estimation with a single packet is sufficient to select forwarding links.
- Additionally, this high temporal stability enables very stable topologies, therefore reducing the network overhead required for topology establishment, and consequently reducing energy consumption

UG-AG and AG-UG links

- Furthermore, environmental awareness has to be integrated into communication protocols for WUSNs. For instance, transmit power can be minimized in dry scenarios, but the WUSN has to be aware of the soil's moisture content to trigger such an action.

Topology

1. 3D topologies will be common in WUSNs, with devices deployed at varying depths dictated by the sensing application
2. Multihop: large number of short hops
3. Cost (deployment and maintenance): minimise number and depth of sensors, but this conflicts with 1 and 2

Topology

- Underground topology: This consists of all sensor devices deployed underground, except for the sink,
- Hybrid Topology: This is composed of a mixture of underground and above ground sensor devices: terrestrial relays on the surface
- Mobile Hybrid Topology: Mobile AG nodes (data mules) communicating with the UG nodes

Power management

- Hard to access nodes to change battery

- Solutions
  - Energy harvesting
  - Ultra-low power hardware and protocols
  - Over provision (large batteries)

Power

- Scavenging opportunities for WUSN devices, such as converting seismic vibra- tions or thermal gradients to energy,do exist, but it remains to be explored whether these methods can provide sufficient energy to operate a device in the absence of a traditional power supply.
- Power conservation, therefore, should be a pri-mary objective in the design of WUSNs

Antennas

- Variable requirements
  - same node comms UG-UG and UG-AG,
  - diff depths have diff reqs
- Size
  - Low frequencies best for UG, but they require long antennas
  - At a frequency of 100 MHz eg, a quarter-wavelength antenna would measure 0.75 m.
- Directionality
  - Uni-direction more efficient than omni-direction, but how to deploy, and more than one may be needed

Deployment

- **Easy:** WUSN devices are deployed completely below ground and do not require any wired connections. Each device contains all necessary sensors, memory, a processor, a radio, an antenna, and a power source
- **Hard:** The installation and maintenance of nodes UG is difficult

Operating Conditions

- Wet
- Temperature extremes
- Animals and insects
- Equipment disturbance
  eg ploughs etc
- Pressure from above ground
  eg passing vehicles
- Installation conditions

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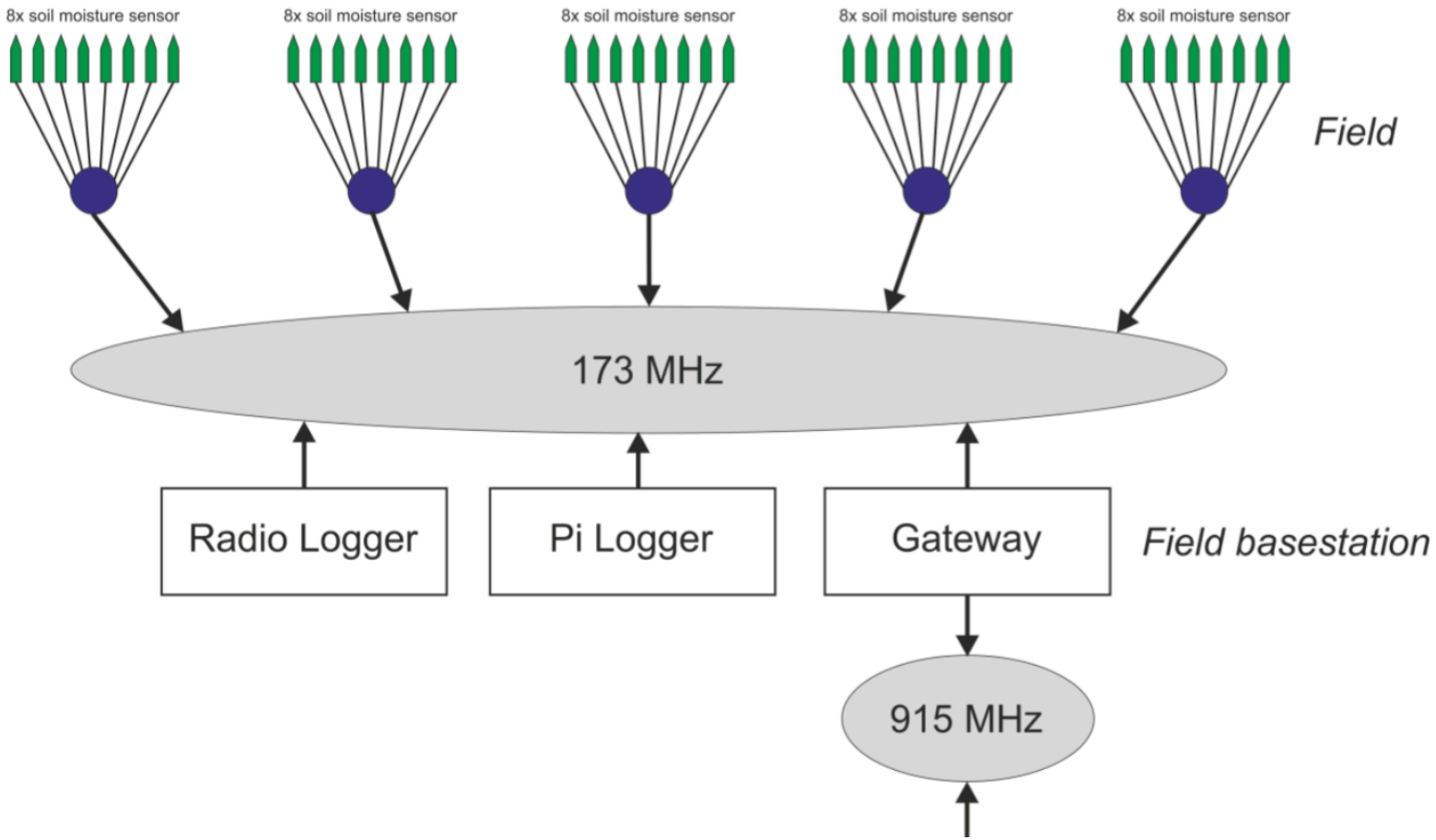
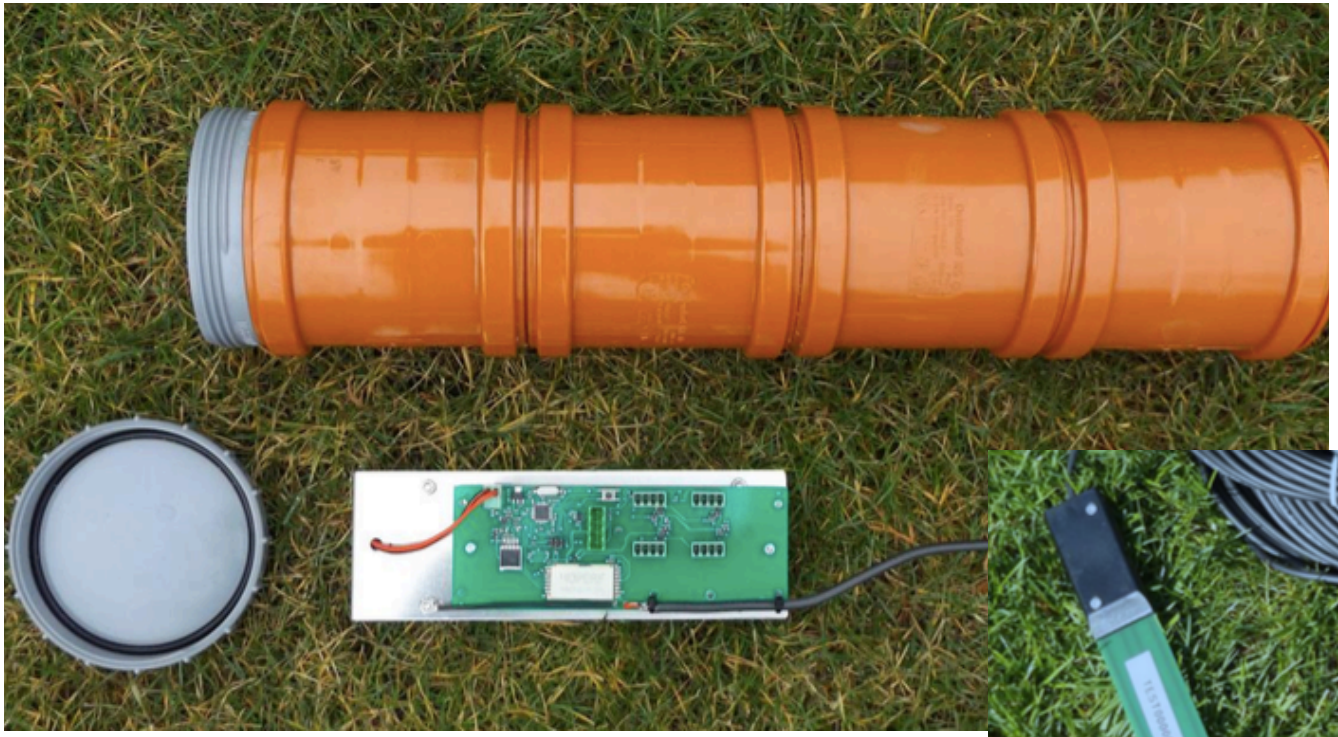
Case study: UWA farm

UWA farm network



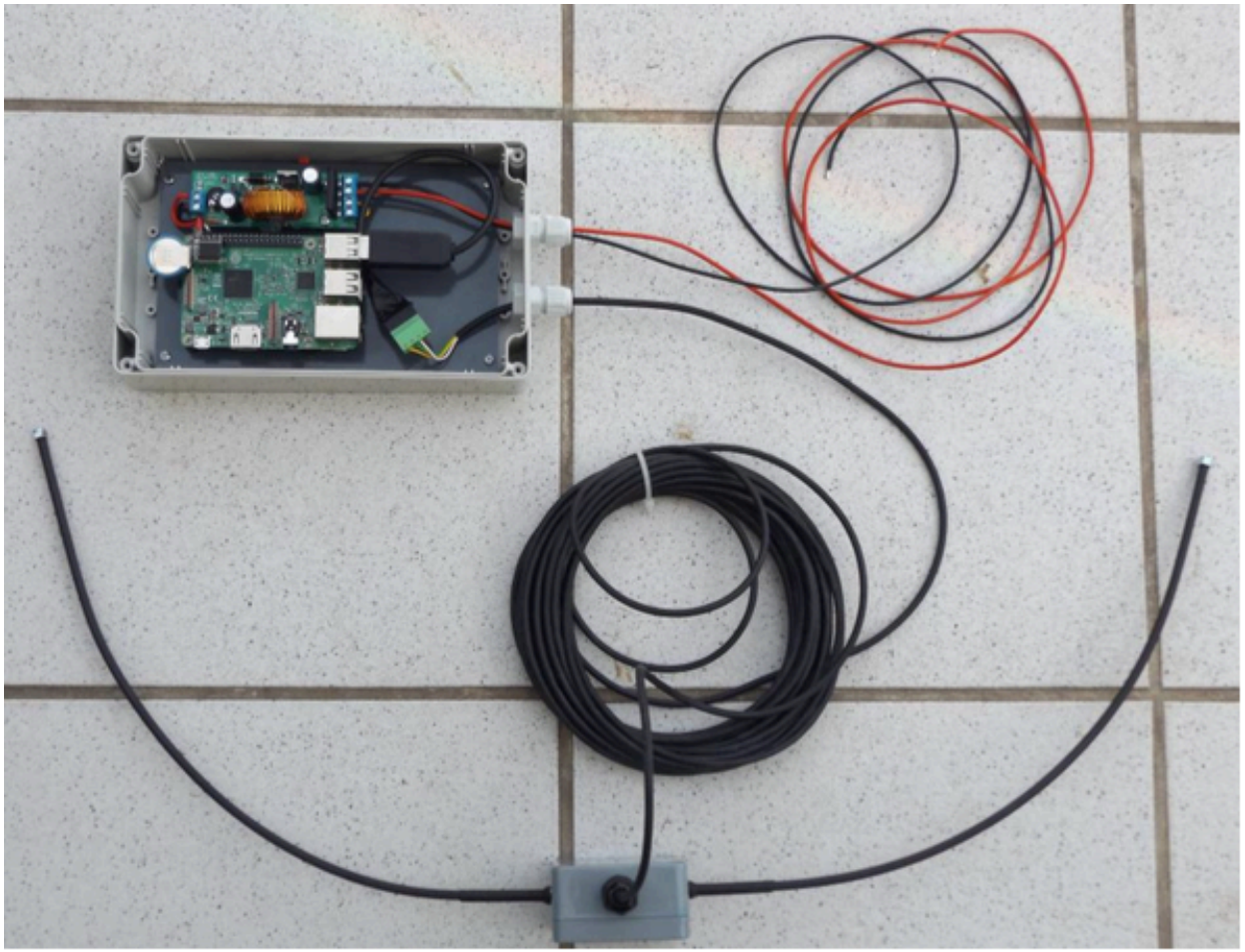
Base station site

Sensor Nodes



Installation

Base station



Summary

- Applications for WUSNs include agriculture, environment, infrastructure monitoring and tracking
- Complex communications with short range UG channels and complex UG-AG channels
- HW considerations are critical: e.g. power, antenna, node housing
- UWA is testing a 173 MHz LoRa underground system on the UWA farm at Pingelly

Ideas for Further Reading

- Experimental Link Quality Characterization of Wireless Sensor Networks for Underground Monitoring, Silva et al, IEEE Trans Industrial Informatics, 11(5) 2015
- Underwater sensor networks