Applications in Process Industry

- Enhance safety, optimize process, protect environment
  - Detect leaks before they lead to environmental problems.
  - Monitor the status of manually operated valves.
  - Monitor safety relief valves to detect venting to avoid accidents.

- Health, Safety, and the Environment (HSE) regulations.
Feedback control loop controls a physical process.

- Example: control temperature by manipulating heat supply.

Centralized vs. peer-to-peer control.
Why Wireless

- **Cost reduction:** wiring is economically infeasible

- **Easier installation:** inaccessible locations

- **Easier maintenance**
  - Wired networks cannot handle severe heat or exposure of chemicals
  - A wireless infrastructure can remain in place for many years.
Challenges in Wireless

- Strict timing requirement
- High security concerns
- Reliable communication despite wireless deficiencies
- Plant environments are inherently unreliable
  - Interference, obstacles, power failures, lightning, storms…
Wireless Technologies

- Existing standards fail in industrial environments
  - **ZigBee**: static channel
  - **Bluetooth**: quasi-static star network

- **WirelessHART**
  - For process measurement and control applications
  - First open and interoperable wireless standard to address the critical needs of real-world industrial applications
History

- **HART (Highway Addressable Remote Transducer Protocol)**
  - Most widely used field communication protocol
  - 30 million devices worldwide

- **WirelessHART released in Sep 2007 (as a part of HART 7)**
  - Adds wireless capabilities to the HART protocol while maintaining compatibility with existing devices, commands and tools.
Wireless for Process Automation

- World-wide adoption of wireless in process industries

1.5+ billion hours operating experience

100,000s of smart wireless field devices

10,000s of wireless field networks

Offshore

Onshore

Killer App of Sensor Networks!

Courtesy: Emerson Process Management
WirelessHART Use Cases

- Improved control of plant steam supply by detecting “cool spots” in cross plant steam lines

- Reducing risk of overfilling tanks by adding redundant level measurements (in oil and petroleum refineries)

- Monitor and control safety valves

- Monitor and control pressure and temperature of process fluids and gases
What is special?

- Reliable: 99.9%
- Secure
- Self-organizing, self-healing
- Interoperable
- Supports both star and mesh topologies
- Built-in time synchronization
Network Architecture

Host Application (e.g. Asset Management)

Gateway

Network Manager

Security Manager

Process Automation Controller

Access Point

Wireless Handheld

Wireless HART Field Devices

Wireless Adapter

HART-Enabled Field Devices
Network Manager

- Centralized brain

- Manages the network and its devices
  - Routing, scheduling
  - User/administrator interacts with the Network Manager
  - Generates network management packets to devices

- Redundant Network Managers supported (only one active)
Field Devices

- Sensor/actuator/both

- Connected to the process or plant equipment

- Combines wireless communication with traditional HART field device capabilities

- May be line or battery-powered
WirelessHART Adapter

- Enables communication with a non-native device through a WirelessHART Network.
One gateway can support up to 80 devices

A Gateway provides

- One or more Access Points providing the physical connection into the WirelessHART network
- One or more Host Interfaces connecting the Gateway to backbone networks (e.g., the plant automation network)
- A connection to the Network Manager
- Buffering and local storage for publishing data, event notification, and common commands
- Time synchronization sourcing
Other Devices

- **Handheld devices**
  - Portable applications used to configure, maintain or control plant assets.
  - Typically belong to networks of different standards

- **Plant Automation Network**
  - Connects client applications to the gateway

- **Security Manager**
  - Industry standard AES-128 ciphers/keys
WirelessHART PHY

- Adopts IEEE 802.15.4
  - Same 16 mutually orthogonal channels
  - Operates in the 2.4GHz ISM band
  - Data rate of up to 250 Kbps

- Radio transceivers
  - Omni-directional
  - Half-duplex
  - 100 meters LOS @ 0 dB
  - Time to switch between channels: 0.192 ms
  - Radio turn-on time: 4 ms
How to achieve reliability?

- Time diversity

- Channel diversity
  - Channel hopping
  - Channel blacklisting

- Route diversity
  - Graph routing

- Power Diversity
TDMA Data Link Layer

- **10 ms time slot**
  - Transmission starts at a specified time after the beginning of a slot
    - Source & destination set channel
    - Allows receiver to begin listening
  - Enough time for transmission + ACK

- **Superframe**: a series of time slots defining the communication schedule of a set of devices
Time Synchronization

- Gateway is the root source of time

- When a device receives a packet
  - $\Delta t = \text{time of arrival} - \text{expected arrival time}$
  - sends $\Delta t$ to the sender via ACK

- Sender adjusts time
Shared vs. Dedicated Time Slots

- A time slot may be shared or dedicated

- **Dedicated** slot: only one sender sends to a receiver

- **Shared** slot: multiple senders attempt to send to a receiver
Shared Time Slots

- Devices contest for access using a contention-based scheme.
  - Behave similar to Slotted Aloha
  - Use collision-avoidance (backoff).

- Using shared links may be desirable when
  - Throughput requirements of devices are low
  - Traffic is irregular or comes in bursts

- May reduce latency since devices do not need to wait for dedicated slot
  - True only when chances of collisions are low
Channel Hopping

- Enhances reliability
  - Avoid interferers
  - Reduce multi-path fading effects

- Blacklisting restricts hopping to some channels

- Each device has a channel map (logical to physical)

- $\text{ActiveChannel} = (\text{ChannelOffset} + \text{ASN}) \mod \#\text{Channel}$
Routing

- WirelessHART supports both Graph and Source routing

- Graph routing: provides redundant paths

- Routing graphs
  - Uplink graph: upstream communication
  - Downlink graph: Downstream communication
  - Broadcast graph
Scheduling

- Slots and channel assignment
  - Each receiver uses a separate channel for reception
  - A transmission is followed by a retransmission on the same link on a dedicated slot, then again on another link on a shared slot

- Each network contains exactly one overall schedule that is created and managed by the Network Manager.

- The schedule is organized into superframes
Superframe

- Transmission Starts
- Destination Listens for Start of Message
- Source Now Listening
- Destination ACK Starts

Transaction

STX

ACK

Cycle n-1
Cycle n
Cycle n+1

Superframe

Slots
Superframe

Cycle N

Cycle N+1

Cycle N+2

Frame 0
5 slots

Frame 1
3 slots

TS0  TS1  TS2  TS3  TS4  TS0  TS1  TS2  TS3  TS4  TS0  TS1

TS2  TS0  TS1  TS2  TS0  TS1  TS2  TS0  TS1  TS2  TS0  TS1
All devices must support multiple superframes

At least one superframe is always enabled while additional superframes can be enabled or disabled

Slot sizes and the superframe length are fixed and form a network cycle with a fixed repetition rate
Data Link Protocol Data Unit (DLPDU)

- Five DLPDU types:
  - Data
  - Keep-Alive (periodic)
  - Advertise (periodic)
  - Disconnect
  - ACK

- Devices receiving a packet with an unknown packet type must not acknowledge the packet and shall immediately discard it.
Network Initialization

- WirelessHART Network automatically starts up and self-organize.

- Before a network can form, a Network Manager and a Gateway must exist.

- The Network Manager activates the first superframe. This establishes the system epoch – ASN 0.

- Once the Network Access Point starts to advertise, devices can begin to join the network.

- As devices join, the network forms.
Network Maintenance

- Advertise and Keep-Alive DLPDUs assist in building and maintaining the device's neighbor list.

- A Keep-Alive must be transmitted to the neighbor if Last Time Communicated > Keep Alive Interval.

- Keep-Alive transmissions are repeated until a new DLPDU is received from the neighbor.

- Keep-Alive no more often than once per 30 seconds (if temperature varies 2° C per minute or less).
Network Maintenance

- Path failures are reported to the Network Manager when devices lose connectivity to neighbors.

- After the Path Fail Interval lapses, a Path-Down Alarm is generated (by both the sender and the receiver).

- As each device's Health Report Timer lapses, the devices generate health reports, which include indications of any problems the device is having with a neighbor.

- Default period of each devices health report is 15 minutes.
Network Maintenance

- Devices continue trying to reestablish communication until the links between them are deleted by the Network Manager.

- It is common for broken paths to be restored after a temporary environmental effect passes.

- If the disruption persists, additional Path-Down Alarms will be generated when the Path Fail Interval lapses again.
Best Practices

- Each field device should have at least three neighbors
  - The 3rd neighbor will act as a backup if one of the two primary paths is obstructed or unavailable.

- Devices (antenna) mounted >0.5m from any vertical surface.

- Devices mounted >1.5m off the ground.

- 25% of the network devices should have a direct connection to the gateway in large networks.