UNITED ELECTRIC CONTROLS

Balancing Safety and Network Considerations in *Wireless*HART® Gas Detection Systems

Recommended practices in toxic and combustible gas leak monitoring.

by: Julian Yeo, Product Manager at United Electric Controls

Detection of toxic and combustible gas leaks is increasingly important for human and environmental protection, but fixed-point wired detectors can only monitor a limited area in a cost effective way. Widespread adoption of the *Wireless*HART network protocol (IEC 62591) and recent advances in lithium battery technology, however, have made it affordable to supplement wired detection systems with wireless systems, improving plant safety and regulatory compliance. This paper addresses recommended practices in implementing fixed-point gas detection across *Wireless*HART networks. We will approach the topic through the lens of life safety at two levels — the device and the network. Although many of the considerations will apply regardless of which wireless protocol is adopted, we have chosen to focus on *Wireless*HART because of its growing prevalence in the market.

Purpose of a gas detection system

Personnel safety drives the intent of a gas detection system design. For toxic gases such as hydrogen sulfide, emphasis should be on frequently trafficked routes and potential escape routes rather than on locating sensors all over the facility.

For combustible gases, such as methane, it is important to distinguish between gas leaks and gas accumulations. While leaks are of some concern, it is accumulations or gas clouds that pose the greatest explosion threat. Emphasis should be on detecting accumulations of sufficient size quickly so that mitigation measures can be implemented immediately. Factors such as obstructions and weather patterns come into play here, but optimizing for accumulation detection is largely a matter of maximizing monitoring density in zones of greatest concern.

Safety device location methodologies

Gas detection layout should be executed in a way that achieves the intent of safeguarding personnel. There are several methodologies that can be employed, two of which are volumetric modeling and scenario-based modeling. Regardless of methodology, it is important to strike a balance between detection effectiveness and cost, which is mainly determined by the number of detectors deployed.

Volumetric modeling

This methodology is used for combustible gases and is based on the size of the target gas cloud. Target gas cloud size refers to the critical volume of combustible gas that if ignited would result in an explosion. Several factors affect the degree of gas explosion, including the level of congestion and confinement of the area concerned.

Volumetric modelling of the target gas cloud is widely accepted for gas detection design. According to the UK HSE publication OTO 93-002, the threshold size for a pressure-inducing explosion to occur is a 6-meter cloud of stochiometrically-mixed methane in a partially enclosed environment. With increased congestion or confinement, it would take a smaller critical volume of gas to be present for an explosion to occur.

As a result, one of the guidelines suggests a 5-meter spacing rule between detectors to detect gas clouds before they can accumulate to a critical volume.

However, in enclosed environments, detector placement is optimized by charting the flow of gas leaks (in addition to accumulations) based on different release scenarios, including release rates and environmental conditions.

Scenario-based modeling

Scenario-based modelling considers various conditions that may affect how a gas leak migrates. The final output is usually a gas map. Gas mapping is a probability analysis that predicts the location of gas hazards and the likelihood of their occurrence. Gas maps are based on computational fluid dynamics models, which use rigorous numerical analysis and algorithms to predict flow of both liquids and gases. These mathematical calculations optimize gas detector placement, factoring in the following:

- Position in relation to assets
- Obstacle analysis
- Environmental conditions such as wind speed and direction

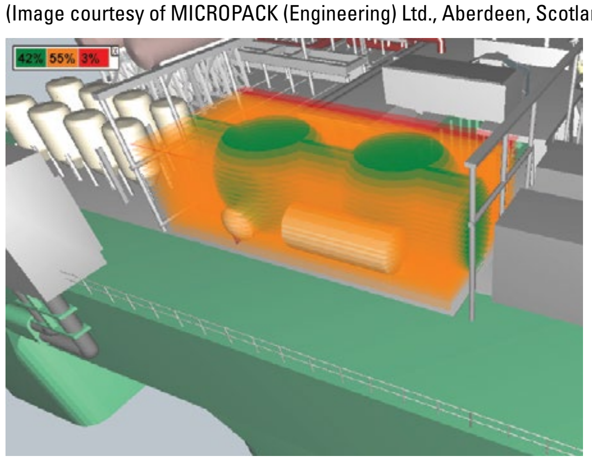
Several software applications (e.g. HazMap3D from MICROPACK (Engineering) Ltd.) are available to assist with gas mapping, including fluid dynamics calculations. Users would simply click on the desired locations of the detectors, enter the coordinates directly, and the detector is added with detection coverage shown. Some of these gas mapping tools come integrated with a library of detector models from various manufacturers.

Where there is more than one detector involved, mapping tools can also indicate where the coverage intersects and trigger corresponding action from the detectors. For example, the green areas in figure 1 show where the target gas cloud will intersect with two devices thus generating an executive action in a 2 out of N (2ooN) voted layout; the orange areas show where the target gas cloud will intersect with one device, thus generating an alarm only (1ooN) in a 2ooN voted layout; and the red areas are where the target gas cloud will remain undetected by the gas detection system.

In figure 2, the HazMap3D software models the dispersion of a gas leak 30 and 150 seconds after occurrence. The red areas indicate the presence of the combustible gas and how it has migrated after a 120-second lapse.

As a recommended practice, gas mapping should be performed at the Front-End Engineering Design (FEED) stage of the project life, right after the conceptual design or feasibility study is completed. When using scenario-based modeling, the user must be mindful that there is no limit to the number of possible scenarios, resulting in a

Figure 1: Detection coverage mapped out using HazMap3D
(Image courtesy of MICROPACK (Engineering) Ltd., Aberdeen, Scotland)



Key
Green = Areas where the target gas cloud will intersect with 2 devices
Orange = Areas where the target gas cloud will intersect with 1 device
Red = Areas where the target gas cloud will remain undetected

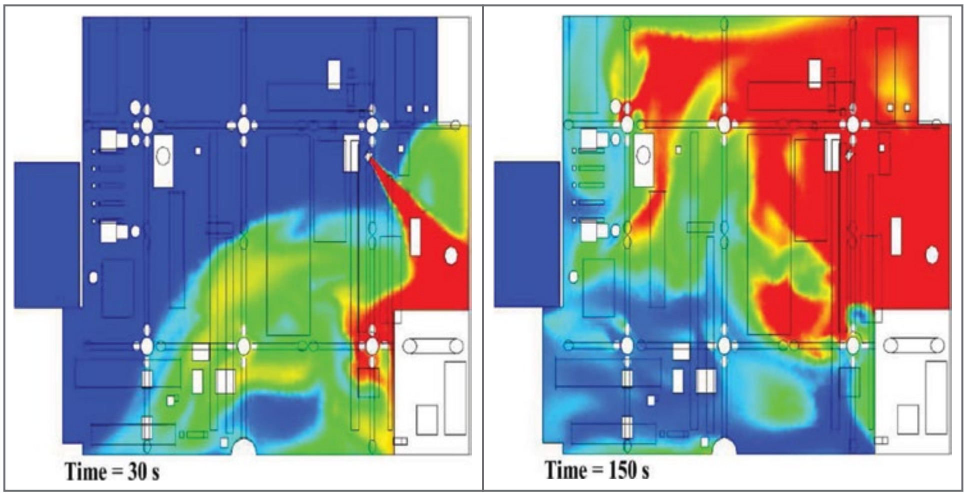


Figure 2: Model of gas leak (red) dispersion 30 seconds and 150 seconds after leakage. (Image courtesy of MICROPACK (Engineering) Ltd., Aberdeen, Scotland)

greater-than-necessary number of detectors implemented. This is again why it is critical to strike a cautious balance between performance and cost.

Other device level considerations

Determining the ideal sensor height is usually based on the personal knowledge and experience of operators. This can be an effective method, but offers no traceability. As a rule of thumb, to detect gases that are lighter than air, such as methane or ammonia, detectors should be mounted at a higher level where the gas is likely to migrate.

For gases that are heavier than air, such as butane and sulphur dioxide, detectors should typically be mounted closer to the ground, but breathing zones should also be considered. Hydrogen sulfide (H_2S), for example is a heavy gas with a breathing zone between 4 to 5 feet above ground.

Detectors should be positioned away from high pressure leak sources otherwise the gas expelled at high speeds may not be detected. Detector orientation also matters. Sensors should, for example, point downwards to prevent dust or water ingression. Where appropriate, the use of accessories such as a collecting cone can help to facilitate ambient sensing of the gases.

Designing the *Wireless*HART mesh network

In addition to device level recommendations suggested, there are methods to optimize connectivity with the *Wireless*HART network. The three key elements in a *Wireless*HART network are (i) *Wireless*HART field devices, (ii) gateways that facilitate wireless communication between the field devices and a wired connection to DCS, AMS or other host systems, and (iii) a network manager that coordinates and optimizes data flow. The number and placement of field devices and gateways can influence network efficiency significantly.

Table 1 summarizes the many considerations involved in developing a reliable *Wireless*HART network design. These include deploying enough sensors on the network to maximize redundancy while not overloading the wireless channel; recognizing potential barriers in the plant infrastructure; optimizing location of routers; setting the range and proximity of sensors to ensure continuous

Table 1: Considerations for wireless network design and layout (source: ISA-TR84.00.08-2017 Technical Report)

Network design consideration	Topology
Minimum number of field devices to use for a reliable redundant network	Mesh/Hybrid
Maximum number of field devices to avoid overloading the wireless channel and infrastructure, while supporting future expansion	Mesh/Star (point to multipoint)/Hybrid
Conservative communication range assumption taking into account infrastructure density and potential sources of interference	Mesh/Star (point to multipoint)/Hybrid
Centrally located wireless infrastructure	Mesh/Star (point to multipoint)/Hybrid
Minimum number of routing neighbors available to provide redundant paths for data	Mesh/Hybrid
Minimum number of field devices within reliable range of wireless infrastructure to avoid bottlenecking data flow	Mesh/Hybrid
Maximum number of hops (retransmissions) to achieve acceptable data delivery latency	Mesh/Hybrid
Use of manufacturer-supplied layout and simulation tools including network stress testing and reinforcement	Mesh/Star (point to multipoint)/Hybrid
Field device update periods configured to provide measurement data within the required timing of the system and adequate battery life	Mesh/Star (point to multipoint)/Hybrid
Mesh network — a network where field devices receive and retransmit data from other field devices. Star network — a network where field devices do not receive and/or retransmit data from other field devices. Hybrid network — a network containing both mesh and star type field devices.	

signals; updating refresh intervals; managing battery life; and using layout and simulation tools. A new *Wireless*HART user might be overwhelmed with this list of seemingly complex considerations but in reality, implementing a *Wireless*HART network is both straightforward and simple.

Table 1 also specifies network topologies associated with each consideration, including mesh topologies in which sensors receive and transmit data from other field devices; star topologies in which sensors do not communicate with other devices; and hybrid topologies, which combine both mesh and star configurations. A mesh topology is used in *Wireless*HART networks.

Recommended practices for maximizing network reliability

Regardless of how well-positioned the wireless gas detectors are for detecting gas clouds, they are ineffective if they cannot communicate data reliably across the wireless network via the gateway. Two factors that impact reliability significantly are redundancy and the distance between devices in the mesh network.

Maximizing redundancy

For maximum redundancy, ensure that each field device has at least three neighbors within the effective range. That way, even if one or two of the primary paths becomes obstructed, there is still a redundant pathway back to the gateway via the third neighbor. These neighboring devices can be instruments from any manufacturer, as long as they are *Wireless*HART compatible.

The FieldComm Group also recommends a minimum of five devices in a *Wireless*HART network. Networks will work properly with fewer than five *Wireless*HART devices, but they will not benefit from the intrinsic redundancy of a self-organizing mesh network, which becomes more robust with the addition of more devices. In a well-formed, well-designed network, new *Wireless*HART devices can be added to the interior or perimeter of the network without affecting operation or extensive consideration for design.

In scenarios in which the *Wireless*HART network has more than five devices, at least 25 percent should be in the effective range of the gateway to ensure proper bandwidth and eliminate pinch points. For example, in a 100-device network, 25 devices should be within effective range of the gateway. *Wireless*HART networks can work with as few as 10 percent of the devices in the effective range of the gateway but results will not be optimal.

Effective range

It is recommended to locate wireless sensors as one would with wired sensors, organizing them by process units within designated plant areas but within the effective range of an in-network device. When there is a clear line of sight, wireless signals can typically propagate around 750 feet, but as illustrated by table 2, obstructions can limit this range significantly.

Other network level considerations

The FieldComm Group, the organization responsible for advancing the *Wireless*HART standard, provides additional recommendations for *Wireless*HART implementation. To facilitate radio signal propagation, the recommended practice is to mount devices more than 1.5 feet from any vertical surface and more than 5 feet above ground. Devices should ideally be at the line-of-sight height which is equivalent to the obstruction height plus 6 feet. It is useful to note that radio signals are also affected by obstructions such as trees, foliage and building materials made from concrete and wood.

In certain subterranean or underwater scenarios, the radio signal is completely absorbed and cannot be propagated. Where it is not possible to relocate these obstacles, adding repeaters to propagate the *Wireless*HART signal could be a simple workaround.

Table 2: Effective Range of wireless connections among plant environments of various obstacle density (used with permission from the FieldComm Group, Austin, TX)

Degree of Obstruction	Description
Clear line of sight — 750 ft. (225 m)	Open areas with minimal change in the terrain level (less than 5-degree elevation). Device antenna mounted at least 6 feet above obstruction height.
Little obstruction — 500 ft. (150 m)	Lots of space between assets to facilitate propagation of radio signals. E.g. tank storage facilities.
Moderate obstruction — 250 ft. (75 m)	A more congested environment but with adequate space to allow a vehicle (e.g. truck) to pass through between equipment and plant infrastructure
Heavy obstruction — 100 ft. (30 m)	A congested environment. Facility is too dense to allow for any vehicle to drive through it.

To help establish the self-organizing mesh quickly, it is recommended to install in the following sequence:

1. Install the gateway first so that the *Wireless*HART devices can connect to the gateway in parallel with gateway-host system integration. This saves commissioning time.

2. Commission the devices closest to the gateway first so that those located farther away can connect through the inner periphery of devices.

3. Allow more than four hours for the network to achieve optimal stability before verifying network operation.

In practice, a strong reliable *Wireless*HART network can easily be achieved as published *Wireless*HART network specifications are intentionally conservative to minimize installation and commissioning issues.

Marrying device and network level considerations

Gas detectors are only useful if they can protect lives. Wireless networks are only as good as its level of reliability. Where device-level considerations conflict with network level considerations, detection device considerations should get priority.

For example, volumetric gas cloud modeling may designate a congested area as prone to gas accumulations and thus in need of gas detection units. If this zone has no neighboring *Wireless*HART devices and populated with concrete buildings, foliage and other potential signal obstructions, it would not be an ideal location for *Wireless*HART communication. In such cases the target cloud mapping should drive the location rather than the optimal network considerations.

Safety is the gas detector's primary function and all considerations to help it fulfill its role should take precedence. The *Wireless*HART protocol is a self-organizing, self-healing mesh network that is flexible enough not to be constrained by device considerations. In our example above, repeaters can always be added in between to strengthen the communication pathways between the gateway and the device.

*Wireless*HART enabled gas detectors offers flexibility to locate anywhere at anytime

Volumetric and scenario-based modeling methodologies have come a long way in identifying appropriate locations for point gas detectors. However, during the life of the plant, equipment and processes are changed and modernized, which can make the modeling analysis outdated. Additional processes with different gases used as a catalyst or gas by-product of the new process could be involved.

Even before the upgrades, the plant can change significantly from "as designed" to "as built" requiring the end user to remodel the gas detector locations, which few do after the FEED stage. Because the modeling software is smart and takes into account many dependent variables (e.g. environment), the result is that the number of gas detectors required would likely increase. The location of the gas detectors would also change after operating the plant for a time. For example, using data from personal detectors, accidents, and near miss accidents, operators can identify unprotected areas requiring increased gas detector coverage.

Fortunately, with the emergence of open source wireless (e.g. *Wireless*HART) gas detectors, these devices can be added anywhere to the existing mesh network easily to create an instant monitoring point, even for brownfield facilities. With *Wireless*HART gas detectors, the total installation cost is reduced, alleviating the financial burden that comes with increasing more detectors. The competing goals of cost-effective and safe gas detection, as well as reliable network communication can now be achieved with a *Wireless*HART gas detector.

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