# iCOMOX: Connectivity Options and Application

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The Intelligent Condition Monitoring Box also known as iCOMOX is an open-source sensor fusion platform designed for Condition-based Monitoring (CbM) applications. The iCOMOX can measure vibration, sound, temperature, and magnetic field displacement. This device can process and transmit the sensor data using three (3) unique communication technologies. The communication options available for iCOMOX are: SmartMesh IP (SMIP), Narrow Band IoT (NB-IoT), and Power over Ethernet (PoE). Choosing an option without fully understanding the tradeoffs can be costly and frustrating. This paper educates the user on the strengths and weaknesses of each communication type for proper application. The intended audience for this paper is anyone interested in deploying a CbM system such as, maintenance professionals, plant managers, and system integrators.

## Contents



## IEEE 802.15.4 Primer

Wireless transmission of data can be unreliable based on several factors. The IEEE 802.15.4 standard operates in the sub-GHz and 2.4 GHz bands. The 802.15.4 standard defines PHY and MAC layers for short-range, and low-power operation. The data bandwidth is intentionally low (about 250 kbps) to conserve power. This makes this standard ideal for Wireless Sensor Networks (WSN). Examples of 802.15.4 radio topologies are Zigbee, Bluetooth, WirelessHART, 6LoWPAN, and SMIP. Figure 1 illustrates the radio spectrum for these technologies and others. However, this is not the only factor to be considered when choosing a low-power wireless technology.

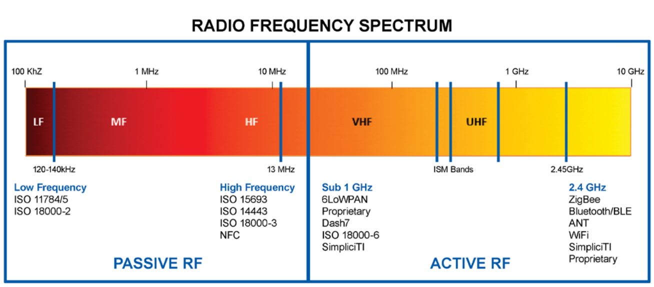

Figure 1. Radio frequency spectrum for passive and active RF technologies.

## Sources of Radio Interference

One factor to be considered is environmental noise interference. The 802.15.4 standard uses spread spectrum technology to provide noise immunity from unwanted sources which may be within the same frequency band. However, the use of the 802.15.4 standard does not guarantee trouble-free transmission and reception of data. Other 802.15.4 radio sources may occupy the same channel and can cause signals to overlap forcing retransmission of data. This leads to unreliable data packet delivery times and excess power being expended due to transmission retries. This becomes a major issue for battery-powered devices that cannot afford to lose precious energy.

Another general problem associated with any wireless system is the phenomena known as multi-path fading. Multi-path fading of a radio signal occurs when a transmitted signal cannot reach it's intended receiver due to physical obstructions between the transmitter and receiver. These physical obstructions can be floors, ceilings, doors, refractory, catwalks, machinery, and even people. Echoes of the radio signal are produced which are reflected to the receiver at different times (and phases) along with the direct signal. This creates destructive interference between the out of phase false signals and the true signal. Multi-path fading can interfere or even completely block wireless data transmission. Figure 2 shows an example of multi-path fading.

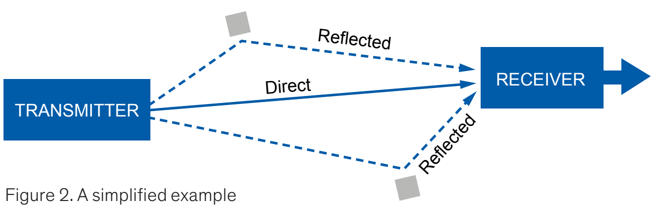


Figure 2. A simplified example of multi-path fading

## SmartMesh IP (SMIP)

SMIP is based on the IEEE 802.15.4 standard and includes features that overcome the previously mentioned sources of radio interference. SMIP is a high-reliability (> 99.999%), low-power, mesh network topology for low bandwidth data transmission (< 250 kbps). It includes comprehensive security management and has a flexible configuration to accommodate specific system requirements. Figure 3 illustrates a high-level SMIP network topology.

A SmartMesh network is comprised of self-forming multi-hop mesh of nodes called motes. An access point mote known as a Network Manager can connect to a PC or Supervisory and Control Data Acquisition (SCADA) system. SMIP utilizes a Time Slotted Channel Hopping (TSCH) link layer to overcome the possibility of other

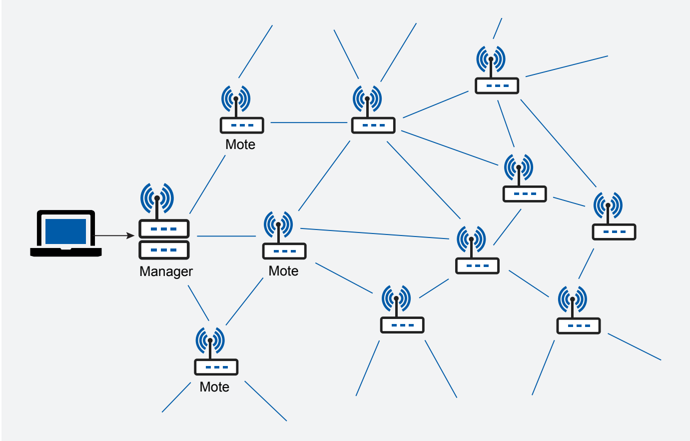


Figure 3. SmartMesh IP Network

802.15.4 radio packets colliding or occupying the same channel. This permits precise time synchronization of all motes on the network within tens of microseconds. Each mote has a dedicated timeslot to transmit and receive data. This feature enables channel hopping for each data exchange. This is key to ensuring low data latency and mitigation of channel interference ensuring high Quality of Service (QoS).

Every mote in the SmartMesh network has one or more parents that provide redundant paths to overcome multi-path fading. If a transmission fails on one path, the next re-transmission may try a different path (or parent) and possibly a different channel (channel hopping). Essentially, each mote is a router. Deployment guidelines need to be followed to ensure correct mesh operation for optimum network performance. Figure 4 illustrates how each mote can be a router to solve the multi-path fading problem.

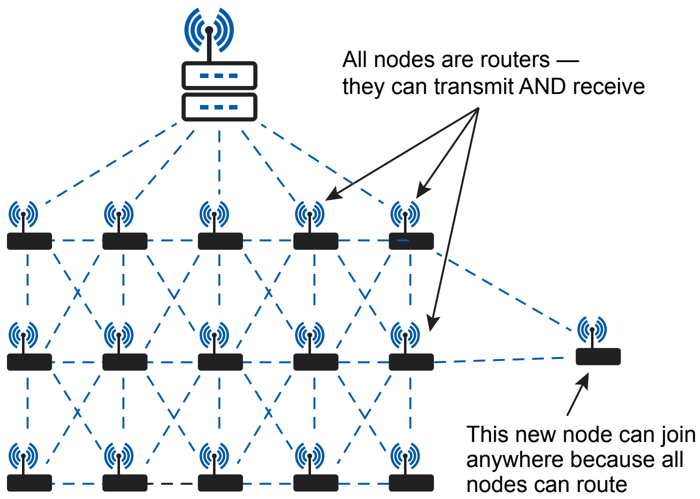


Figure 4. All nodes are routers in a SmartMesh network

## Narrow Band IoT (NB-IoT)

Narrow Band IoT is a 3GPP (cellular) standardized radio technology. NB-IoT bandwidth is limited to 180 kHz. It occupies the guard band between LTE carriers which is 200 kHz (see Figure 5). The narrow bandwidth limits the peak data rate to about 250 kbps. Cat-M1 is another 3GPP variant of NB-IoT and can operate up to 1.4 MHz bandwidth outside the guard band. Cat-M1 can achieve data rates as high as 1 Mbps and can support voice calls due to the higher bandwidth than the NB-IoT standard. Hence, the "M" in Cat-M1 which stands for mobility.

NB-IoT radio is still subject to the laws of physics and as such the same sources of radio interference apply. However, environmental noise and channel interference from cellular phones are mitigated for the most part due to the use of the LTE guard band along with the inherent operation of LTE networks. Multi-path fading becomes the major issue to contend with regarding the use of NB-IoT radio for sensor networks but on a much larger scale.

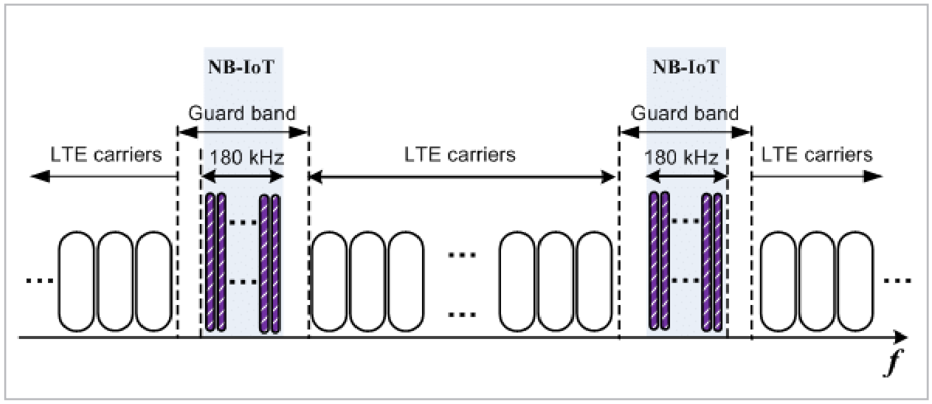

Figure 5. LTE guard band with NB-IoT

As discussed, NB-IoT piggy-backs onto LTE cellular networks by using the guard band. LTE network operation depends upon radio towers (base stations) judiciously spaced apart to create what are called "cells" to form a coverage area. The base stations within each cell broadcast at limited power. This permits reuse of the same frequencies by other base stations located in adjacent cells without the threat of interference from one another. The size of the cell (coverage area) is dictated by the amount of traffic (users) within that area. The quality and reliability of a cellular network depends on the size of the cells, the geographic terrain where they are located, and any obstructions which can block, diffract, or scatter the radio signal. Figure 6 is a diagram showing how terrain and obstructions can affect the quality of a cellular radio signal. We all experience this phenomena when traveling in cars where our conversations "drop" as we drive through different landscapes. This could be due to the number of towers (base stations) in that area as well as multi-path fading as shown below.

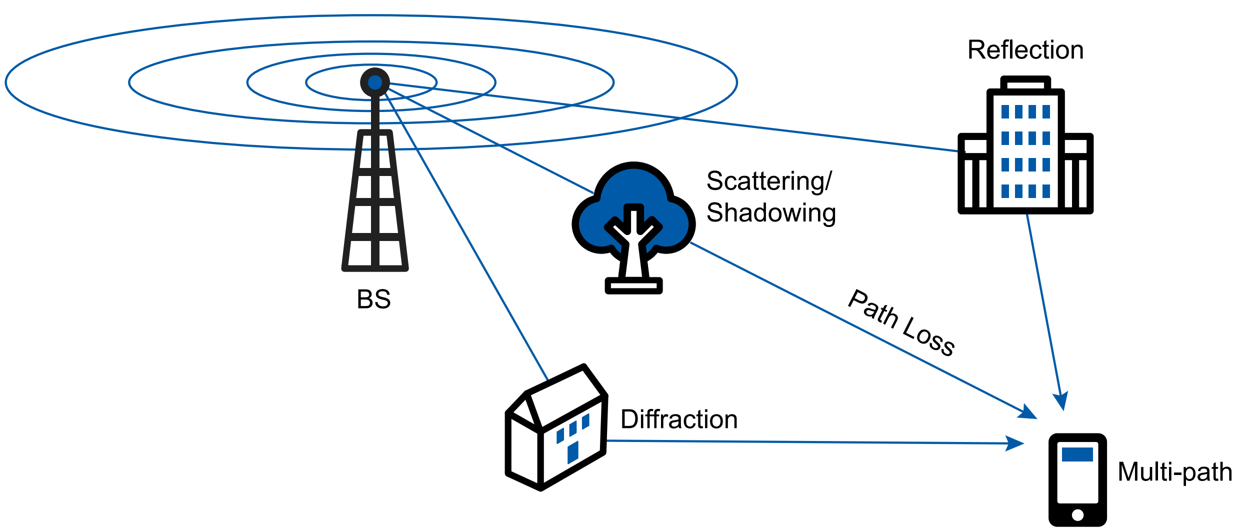

Figure 6. Example of cellular radio multi-path fading

## Power over Ethernet (PoE)

Power over Ethernet (PoE) is a relatively new IEEE standard to convey power and data over the same cable connection. The Power Sourcing Equipment (PSE) connects to a Powered Device (PD) to provide power, data, or possibly both depending upon the equipment. The IEEE has set standards for power delivery to the PD for various PoE types. These types are outlined in Table 1. The iCOMOX PoE is a Type 1 PD and uses the LTC4267 PD Interface with integrated switching regulator. The LTC4267 enables a complete power interface port solution for Type 1 PDs.

| PoE Type | Type 1 | Type 2 | Type 3 | Type 4 |
|---|---|---|---|---|
| Name | PoE, 2-pair PoE | PoE+ | 4-pair PoE, 4P PoE, PoE++, UPOE | Higher Power PoE |
| IEEE Standard | 802.3af | 802.3at | 802.3bt | 802.3bt |
| Max Port Power | 15.4W | 30W | 60W | 100W |

Table 1. PoE Types

## 802.3 Network Deployment Considerations

Deployment of a wireless or wired network requires pre-planning. Several precautions should be adhered to before routing cable for an 802.3 network. The first is the choice of cable to support the peak network data rate. Table 2 is a chart of the different categories of Ethernet cable and their characteristics. The iCOMOX POE supports up to 100 Mbps (100Base-T) data rates. Therefore, Cat5 or Cat5e cables are good choices.

| Cable Category | Cat5 | Cat5e | Cat6 | Cat7 | Cat8 |
|---|---|---|---|---|---|
| Shielding | UTP | UTP | STP/UTP | STP | Unreleased |
| Max Data Rate | 10/100 Mbps | 1000 Mbps | 1000 Mbps | 10000 Mbps | Unreleased |
| Max Bandwidth | 100 MHz | 100 MHz | >250 MHz | 600 MHz | Unreleased |

Table 2. Ethernet Cat Types

Ethernet cable can be purchased with Unshielded Twisted Pairs (UTP) or Shielded Twisted Pairs (STP) wiring. 802.3 data is transmitted at very high rates of speed as differential signals over pairs of conductors which are twisted together. This was intentionally designed in this manner to minimize radiated emissions (EMI) coming from the cable. Think of it as one long antenna propagating unwanted RF signals. The use of STP cable has a two-fold benefit: it helps to further reduce EMI, and it protects the data from corruption by other sources of environmental noise.

Cable run length, known as “reach” also varies depending upon the 802.3u specification. Table 3 shows the maximum reach based on the most widely used 802.3u specification for industrial applications.

However, the type of cable, network type, and cable run lengths are not the only factors to be considered. Network topology, improper shield grounding, proximity to other noise sources such as motors and fluorescent lighting can all affect the QoS for an 802.3 network. Most 802.3 networks have a maximum reach of about 100 meters. When coupled with PoE technology the reach will be reduced further due to voltage drops across the cable. Selecting the correct cable conductor thickness is essential to lessen these drops. Each application is different and therefore, all factors must be given careful consideration before designing a PoE network architecture.

| 802.3u Spec | Cable Shielding | Max Reach |
|---|---|---|
| 10Base-T | UTP | 100 meters |
| 100Base-T | UTP | 100 meters |
| 100Base-TX | UTP | 220 meters |

Table 3. Ethernet Cat Types

## To the Cloud and Beyond

The power of CbM is revealed through data analytics. Most low-power sensing devices do not have the horsepower to perform adequate data analytics at the edge (point of sensor contact). The iCOMOX is an exception to this rule and can support advanced data processing through custom programming. Most data analysis for large-scale CbM deployment is performed in the Cloud. The Cloud is confusing for many people as to what it means and does. Think of it as a massive collection of computers in a different location on the planet which you can connect to over the internet. Access to this awesome computing power is obtained through cloud services such as Microsoft Azure or Siemens MindSphere. These subscription-based services allow the user to create a custom interface known as a “dashboard” to collect, analyze, and act based on the data coming from the CbM system. However, additional equipment is required to connect your CbM sensor network to the Cloud.

Figure 7 shows the entire range of iCOMOX connectivity options and the required equipment to connect edge components to the cloud service. Please note that the iCOMOX SMIP requires a gateway to convert the SmartMesh IP protocol to Ethernet packets. Figure 8 shows the choices of SMIP gateways which are commercially available. iCOMOX PoE requires a switch with PSE functionality to power each iCOMOX on the network. The iCOMOX NB-IoT uses the cellular network backhaul to communicate sensor data back to the Edge Server.

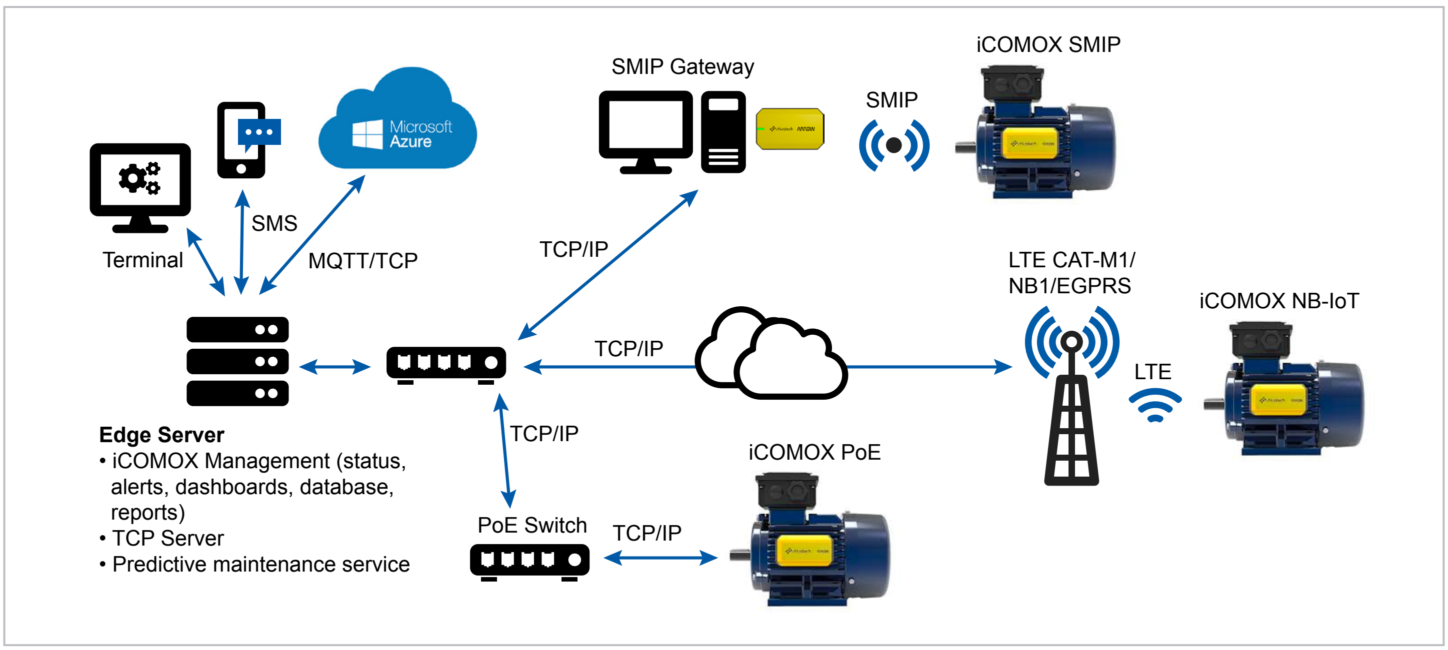


Figure 7. iCOMOX Connectivity Options and Required Additional Equipment

**Embedded Planet EP M2M Wireless Manager for SmartMesh IP**

**Advantech WISE-3310 Wireless IoT Mesh Network Gateway**

**Harting MICA: Modular Industrial Computing Architecture**

Figure 8. Commercially Available SmartMesh IP Gateways

## Putting It All Together

Table 4 shows each iCOMOX connectivity option and associated characteristics. The table below outlines the differences in the connectivity options and best fit based on application type. For example, when using iCOMOX SMIP the network reliability is fully dependent upon the judicious deployment of a mesh network. However, the data rate is low and if simultaneous sampling of raw sensor data is required, the iCOMOX PoE may be a better choice. Yet another example to consider is if you require to extend your CbM system outdoors over longer distances. Both the iCOMOX SMIP and iCOMOX PoE may not be suited to this task depending upon the distance. But, the iCOMOX NB-IoT can connect to cellular towers without additional equipment at a lower data rate. These are a few tradeoffs to be considered before deployment. Also, combining the various connectivity options to extend an iCOMOX network can enable a full coverage indoor/outdoor CbM solution.

| | Raw Data Rate | Range\Reach | QoS | Additional Equipment | Best Fit |
|---|---|---|---|---|---|
| **iCOMOX SMIP** | <250 kbps | Dependent on line-of-sight and obstructions | 99.999% with properly installed mesh network to avoid multi-path fading from obstacles | Yes. Gateway required | Indoor installation for low BW transmission of data where many obstructions are present |
| **iCOMOX NB-IoT** | Cat-NB1 <70 kbps<br>Cat-MI <375 kbps | Dependent on line-of-sight with tower | Dependent on tower location and environment | N/A | Outdoor installations for low BW transmission of data with clear line-of-sight. Cat-NB1 and Cat-M1 are preferred for NB-IoT. EGPRS will consume more energy and is not recommended. |
| **iCOMOX PoE** | 100 Mbps | 100 meters | Dependent upon TCP/IP or UDP packet delivery and adherence to installation rules | Yes. PSE enabled router required | When high raw data BW is required. Dependent upon max reach, PSE availability, or can be used to bridge other networks such as SMIP |

Table 4. iCOMOX Connectivity Options and Characteristics

## Conclusion

The Intelligent Condition Monitoring Box (iCOMOX) is a full-featured CbM monitoring solution that can be customized for specific applications. The addition of SMIP, NB-IoT, and PoE connectivity options expands its use to overcome environmental obstacles that can hinder other CbM systems. Understanding the strengths and weaknesses of each connectivity option before deployment is critical to first-time success with the iCOMOX.

CbM can be made extremely powerful with insights and predictive capabilities when deep data analytics are performed in the Cloud. Subscription services such as Microsoft Azure or Siemens MindSphere are used to process the sensor data to make informed maintenance decisions for valuable industrial assets. Additional equipment may be required to connect to the Cloud or SCADA system. The investment required to deploy a CbM system with iCOMOX is offset considerably by the value returned in mitigated asset maintenance and replacement costs.

## References

> iCOMOX Data Sheet, Shiratech Solutions.

> iCOMOX User Guide, Shiratech Solutions.

> SmartMesh IP User Guide, Analog Devices, Inc.

> Wireless Sensor Network Challenges and Solutions, Dust Networks Product Group, Linear Technology Corp.

> LTC4267 Data Sheet, Analog Devices, Inc.

> KSZ8851SNL/SNLI Single Port Ethernet Controller Data Sheet, Microchip Corp.

> Ethernet Cables: Types, Performance & Pinout

## About the Author

Richard joined Analog devices nine years ago and has worked in several business units during his tenure. He has broad hardware and software design experience obtained over 30 years. He has worked in companies ranging from startups to large corporations and has held various field, design, and technical leadership positions. He is currently focused as a Broad Market Technologist working globally with Arrow Electronics to develop platforms and solutions featuring Analog Devices' technology. Richard holds a BSEE (cum laude) and MSEE Certificate in Engineering Management from Drexel University in Philadelphia, Pennsylvania. You can reach him at richard.matsick@analog.com.