WHITE PAPER

TEXAS INSTRUMENTS

# Long-range RF communication: Why narrowband is the de facto standard

**Terje Lassen**
*Product Line Manager,*
*TI Industrial Low Power RF*
*Texas Instruments*

## Executive summary

*A key parameter for a wireless communication system is the communication range. Fundamentally, the range is dictated by the communication data rate. There are several technical options to increase range by reducing data rate. Two solutions are compared here; scaling the receiver bandwidth to the signal to reduce noise seen by the receiver (narrowband system), and adding coding gain on a higher rate signal to combat the high receiver noise in a wideband receiver.*

*It is shown that adding coding gain for long range communication will negatively affect system performance by:*

- *Greatly reducing spectrum efficiency, i.e., reducing the number of devices that can communicate in a given area, opposite of the industry trend to increase number of radio frequency (RF) nodes*
- *Reducing coexistence properties (protection against interference), which further reduces communication reliability and number of devices in a given area*
- *Decreasing battery lifetime as coding gain signals need very long leader sequences to recover the information signal from the very strong noise component*

*Narrowband communication is a proven way of achieving long-range RF communication and offering superior availability and scalability versus systems based on coding gain principles.*

## Introduction

A key parameter for a wireless communication system is the communication range. In many cases the range application requirements will be the deciding factor when choosing an RF solution. In this white paper, we will use the typical requirements of an RF-enabled water or gas meter to discuss technology options for long-range RF communication, but the factors are also valid for most other types of battery-operated RF nodes. Water and gas meters, often referred to as flow meters, are battery driven and typically have a battery lifetime requirement of between 10 and 20 years. The long battery lifetime puts strong restrictions on choice of network architecture. To be able to guarantee battery lifetime, these meters mostly use a star-network topology, since using these meters as repeaters/routers will make battery lifetime non-deterministic, and challenge the battery lifetime requirements.

Sub-1GHz
Low Power, Robustness, Long Range

In a deployment, the network consists of many meters and few concentrators to collect metering data. The concentrator is typically a more costly node than the meter, since the lower volumes make it possible to have more advanced radios (e.g., software-defined radio), high-current low-noise amplifiers (LNAs) (typically mains powered), better antenna technology, SAW filters, etc. To get wide coverage the concentrator must also be put in a good spot for RF. These types of basestation spots usually carry a relatively high yearly fee; hence the number of concentrators needs to be as low as possible. In a star network topology, the longer the range of the RF links, the fewer concentrators are needed.

## Range considerations, narrowband versus coding gain solutions

For a given output power (often defined by governmental RF regulations), the range of the RF link is determined by the data rate, i.e., lower rate provides longer range due to increased sensitivity for the receiver. There is, of course, also a trade-off, since very low rates mean very long time on air, which will in turn reduce the battery lifetime. Having very long telegrams also increases the probability of interference/collisions with other wireless systems. So in practical installations, long-range systems typically use a reasonably low data rate, typically down to ~1 kbps, to optimize the range and transmission time balance. Narrowband technique for long range and reasonably low date rate is widely accepted by the industry since it gives the optimum tradeoff between range and the transmission time.

Narrowband systems are defined as having less than 25 kHz bandwidth and provide an excellent link budget due to low in-band receive noise (narrow receive filters remove most of the noise). 12.5-kHz channel spacing with 10-kHz receive bandwidth is commonly used. Examples of such systems are police and safety radios, maritime communication systems, social alarms and the new 169-MHz wireless M-bus (wM-Bus) standard for metering applications in Europe. For wM-Bus, 169-MHz narrowband was chosen to get maximum range for water and gas meters to enable fixed network deployments with very few concentrators.

As mentioned above, the range is fundamentally determined by the data rate. An alternative to narrowband communication is to use wideband, high-data-rate communication and add coding gain. Using coding gain does not improve the sensitivity or range; it is simply another way of representing the data. Given the same net data rate/throughput, narrowband and coding gain systems will have similar range. This is easiest to see by means of an example.

A key parameter of an RF system is the receive bandwidth (RXBW). The receive bandwidth is a major factor in setting the noise floor of the system; PdBm = –174 + 10log10 (RXBW), i.e., the noise floor scales with the receive bandwidth (–174 dBm is the thermal noise floor at room temperature in a 1-Hz bandwidth). Using this formula, we can calculate noise floor for different channels:

1-MHz channel: $P_{dBm} = -174 + 10\log10(1\text{ MHz}) = -114\text{ dBm}$
100-kHz channel: $P_{dBm} = -174 + 10\log10(100\text{ kHz}) = -124\text{ dBm}$
10-kHz channel: $P_{dBm} = -174 + 10\log10(10\text{ kHz}) = -134\text{ dBm}$

As seen above, a 10× increase of RXBW increases the noise floor by 10 dB. To get the same range as an uncoded 12.5-kHz narrowband system, 10 dB coding gain must be used for a 100-kHz system and 20 dB coding gain must be used for a 1-MHz system. This example shows the coding gain does not offer increased sensitivity over a narrowband system; it is just a different way of representing the data. Adding more coding gain will not help, as then you need to either reduce the net data rate or increase the RXBW to fit the signal. It is important to understand this fundamental relation when doing trade-offs for long-range RF communication systems.

## Drawbacks with coding gain solutions

The main drawback of using a coding gain solution is the very low spectrum efficiency. The example above shows this very clearly. Compare sending a 1-kbps signal in a 10-kHz channel using narrowband versus sending the same 1-kbps signal in a 100-kHz channel using coding gain. The waste of spectrum is quite obvious, as you send a lot of redundant data in the coding to compensate for the higher noise floor. It is easy to see that in the same 100-kHz bandwidth used for coding, there is room for ten narrowband channels. Network capacity is hence a major drawback of coding gain solutions.

Trading higher receive sensitivity for less spectrum efficiency (higher bandwidth) by spread spectrum goes against regulatory requirements and worldwide industry practice for better spectrum utilization. The growth in demand for wireless connectivity has increased the demands on radio spectrum around the world. Governments and regulatory bodies are placing increasing pressure to improve radio systems' spectrum efficiency.

Narrowbanding to 12.5 kHz and even ultra-narrowbanding to 6.25 kHz RF channels are both well-established solutions to increasing spectrum efficiency.

- **Narrowbanding mandate by FCC:** On January 1, 2013, all public safety and business industrial land mobile radio systems operating in the 150–512 MHz radio bands must operate using minimum 12.5-kHz equivalent efficiency technology, i.e., at least 9.6 kbps throughput per 12.5-kHz channel.

This mandate is the result of an FCC effort to ensure more efficient use of the spectrum and greater spectrum access, which effectively ban use of coding gain schemes for frequencies below 512 MHz in U.S. Similar trends can be seen in Europe and other regions to formally enforce spectrum efficiency.

## *Coexistence*

Since coding gain is used, it is possible to have several orthogonal codes in the same channel, but then the protection between these is given by the coding gain only. In the above example, having 10-dB coding gain, will give less than 10-dB protection against another meter in the same channel. A **SimpleLink™ Sub-1GHz CC1120 smart RF transceiver**-based narrowband system provides up to 65 dB protection from the adjacent/neighbor channel – a 55 dB difference compared to using coding gain. 55 dB will give a dramatic difference in robustness and coexistence in a real-life deployment, translating to a 55-dB improvement in sensitivity in the presence of interference.

Figure 1 on the following page compares the two scenarios, the first one without interference and the second one with interference. As can be seen, weaker co-existence properties translate directly to reduced range.

Considering the example in Figure 1 below, you can have 10 narrowband systems operating in the same bandwidth as a 100-kHz coded system, but you will quickly have major communication problems even when trying to operate only two coded systems in the same bandwidth because of interference.

Additionally, the long duration of the coded transmission makes it vulnerable to interfering signals (transmission collisions). Since the system operates at a low rate at a wide bandwidth, it is simple to show mathematically that the system is robust to one narrowband interferer. This scenario is shown in Figure 2 to the left below. The coded signal (grey) will be able to operate even if the narrowband interferer (red) is present. Due to the large bandwidth used, this is not a particularly relevant scenario. As seen on Fgure 2 below, since

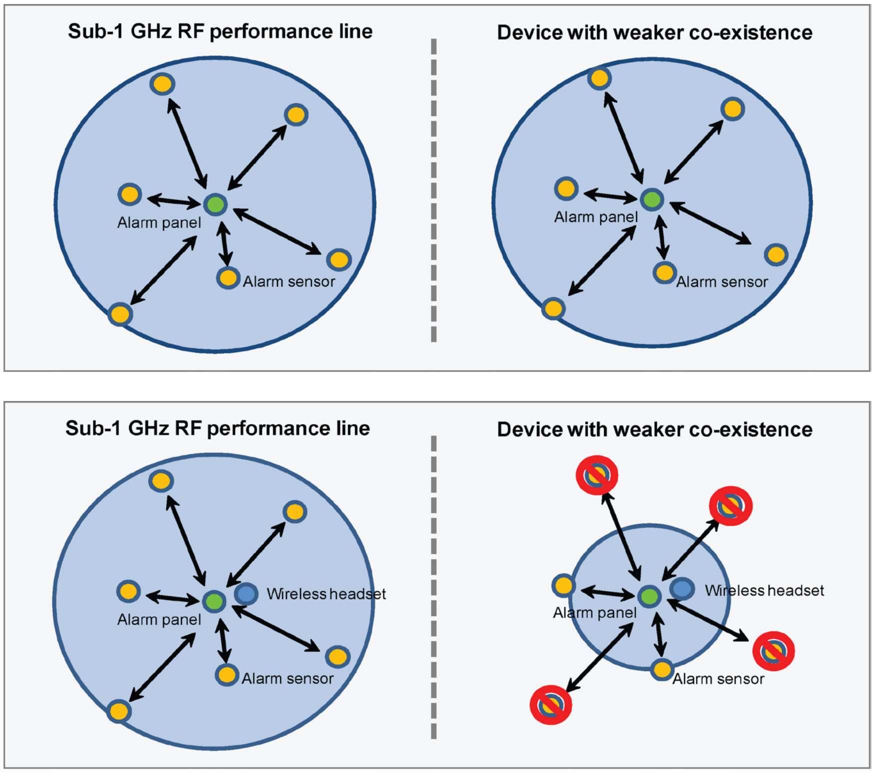

*Figure 1. Typical example of alarm systems without interference (top image) and with interference (bottom image) showing the importance of coexistence properties on performance*

the bandwidth used is big and the data rate low (i.e. time on-air is long), there is a high probability of collision with many narrowband interferers, shown in Figure 2, to the right. This situation cannot be handled by coding gain and will dramatically reduce the practical range of the coded system.

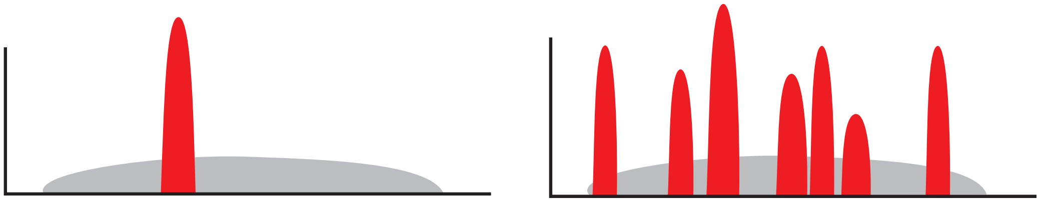

*Figure 2 . Wideband coded system vs. narrowband interference*

## Transmission time

Since the net data rate/throughput is the same for the two scenarios, the payload part of the packet will be a similar length. However, the signal seen in the receiver is very different. Consider the eye diagram plots in Figure 3.

The one to the left is a narrowband signal, where you can see the eye opening clearly distinguish the 0s and 1s in the packet, i.e., the “eye is open.” This signal can reliably be received with as little as four bits of preamble with the high-performance WaveMatch technology of TI’s **CC1120/CC1200 smart RF transceivers**.

The one to the right is the same eye diagram for a system using coding gain. As expected, the signal is not visible, as it is buried below the noise floor. To extract any meaningful information from this signal, you first need to accurately synchronize to the coding scheme to get the required coding gain. Needless to say, this will require a very long preamble or leader sequence before the actual data can be received. When using schemes with high coding gain, the leader sequence will be by far the most dominating part of the message, further reducing the spectral efficiency.

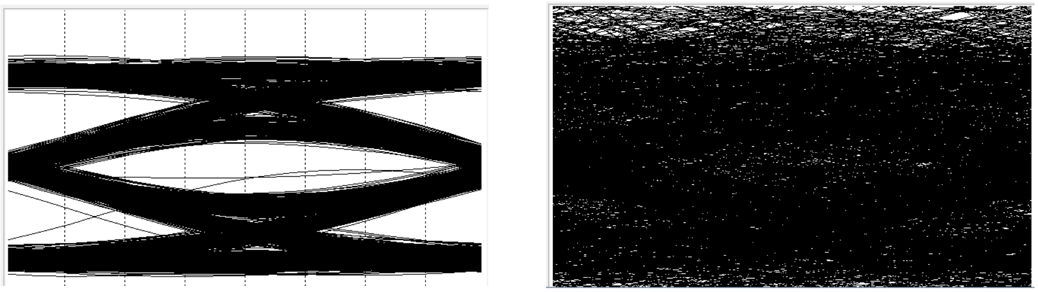

*Figure 3 . Eye diagram uncoded vs. coded signal*

Below is a comparison of actual packet length in the scenario of coded and uncoded packet.

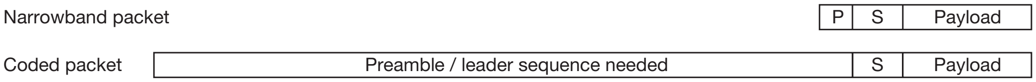

*Figure 4 . Packet format, P=preamble, S=synchronization word / SFD*

The long leader sequence has a strong negative effect on the battery lifetime as a lot of redundant information must be transmitted to enable the receiver to find the wanted signal from below the noise floor. The relation between coding rate and leader sequence length does not scale linearly. For example, doubling the coding rate, or halving the net data rate to get better sensitivity, will increase the length of the leader sequence by a much bigger factor than two, thus reducing the spectrum efficiency and battery lifetime further.

## Frequency accuracy

The drawback of a narrowband system has traditionally been the higher requirements on the RF crystal. A frequency error on the RF crystal leads to an offset on the programmed RF frequency. If the offset gets too big, the signal will fall outside the channel, and be filtered out by the strong receive filters. Legacy narrowband systems typically use temperature-controlled oscillators (TCXOs). These have been more expensive than standard crystals, but the difference has been drastically reduced. Today, however, the accuracy of standard crystals are greatly improved, and when combined with the novel WaveMatch and feedback frequency offset to phase-lock loop (PLL) functionality of the CC1120/CC1200 Sub-1GHz smart RF transceiver family, a narrowband system can be designed with a standard crystal. Given the typical star network topology, it is also simple to compensate for frequency errors from a tighter tolerance reference in the concentrator.

## Technology availability and practical range

The CC1120/CC1200 smart RF transceivers are part of a mainstream ecosystem of standardized, open solutions based on frequency-shift keying (FSK) narrowband technique for long-range communication. Narrowband technology is a well-known, proven technology, supported by multiple vendors in mass production, which is important for long-term availability, product evolution and system price levels.

TI focuses on the complete system solution to provide great RF performance over the air under realistic conditions. This includes low-cost reference designs with high-performance PCB antennas, documentation with wide availability of application notes and design notes, online resources and strong worldwide support teams to ensure maximum range for any given application. TI also focuses on real-life testing, shown in videos of practical range using CC1120 on TI.com:

Practical range tests using standard CC112x kit out-of-the-box:

A **video** showcasing more than 25 km range demonstrated in Cape Town, South Africa using 1.2 kbps and +14 dBm output power:

A second **video** demonstrating more than 10 km range demonstrated in Oslo, Norway using 1.2 kbps and +14 dBm output power

## Conclusion

This white paper has focused on the use of narrowband versus coded wideband system for long-range communications. As demonstrated in the paper and in the comparison chart below, the de facto technology for long-range communication is narrowband due to the superior performance in modern RF systems. For more information on TI's low power RF solutions for narrowband networks, please visit **www.ti.com/rfperformanceline**.

| Parameter | Narrowband | Coded wideband |
|---|---|---|
| Spectrum efficiency | High | Very low |
| Protection against other channels | 65 dB (market leading) | 10–20 dB (very poor) |
| Preamble / leader sequence length | Short, down to 4 bit | Very long, typically 10s to 100s of Bytes |
| Battery efficiency | Good, TX and RX dominated by payload data | Low, TX and RX dominated by leader sequence |
| Availability | Multi-vendor, proven technology | Single source, proprietary, locked IP |
| Frequency accuracy | With novel features such as WaveMatch and feed-back to PLL, the crystal accuracy requirements are greatly reduced, TCXO can be eliminated | Standard crystal can typically be used |

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