Evaluating Fixed Wireless Data Transmission Options within the E-Band

Conventional QAM Modulation versus Impulse Radio Technology

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Introduction
Network operators and service providers seeking to address increasing data communications traffic are likely to encounter situations and locations where fiber is not an option. Consequently there is growing demand for larger capacity radio transmission in these instances. Meeting this demand using conventional modem technology will require a wider frequency band and an array of multiple radio channels. Unfortunately, this seemingly logical solution is neither economically nor practically feasible. There are, however, a number of fixed wireless alternatives available.

Several high-capacity data transmission applications are currently being deployed or evaluated in the field using fixed wireless links over short distances. In most cases, they have proved to be suitable alternatives to fiber. A few relevant examples merit particular mention:

- **Common Public Radio Interface (CPRI) fronthaul** – High-capacity, high-speed In-Phase/Quadrature-Phase (IQ) data transport between remote radio heads (RRHs) and centralized baseband units (BBUs) in next-generation Cloud Radio Access Network (C-RAN) mobile architecture.
- **Ethernet backhaul** – Ethernet traffic from small cells to a mobile operator's PoP location.
- **Metropolitan Point-to-Point (P2P)** – High-frequency financial trading or business data connectivity on rooftops.
- **Rapid data deployment** – Emergency data traffic during disaster recovery or deployment in military, government and municipal infrastructures.

Fixed Wireless Transmission in the E-Band
Fixed wireless communication in the E-band is an increasingly attractive option, since the fundamental characteristics of E-band make it less susceptible to attenuation, distortion, and interference. Currently, there are a number of competing or complementary fixed wireless data transmission technologies in the E-band radio communication space to address growing data communication problems.

In this paper, we evaluate some of the differences in performance and characteristics of data transmission methods used in fixed-wireless E-band radio.

Data Transmission Technology in E-Band – Conventional Modulation versus Impulse Radio
A variety of conventional techniques are used for modulating data signals onto a carrier. They include On-Off Keying (OOK), Frequency Shift Keying (FSK), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK) and Quadrature Amplitude Modulation (QAM).

For the purpose of comparison with Impulse Radio (IR), we will focus on QAM as the industry's most widely used radio communication modulation method. We also generalize all QAM modulation techniques to y-QAM where $y=2^x$ and x could potentially range from 4, 5 ... 12 for practical communication systems. With this generalization, the possibilities are 16-point QAM, 32-point QAM, 64-point QAM, 128-point QAM, 256-point QAM, 512-point QAM, 1024-point QAM, and 2048-point QAM.

Quadrature Amplitude Modulation

QAM is a method in which two carriers, I and Q, which are shifted in phase by 90 degrees, are modulated by sinusoids. The resultant output consists of both amplitude and phase variations; thus QAM may also be viewed as a mixture of amplitude and phase modulation.

QAM is the most widely used form of conventional data modulation. However, in most practical communications systems, FSK and BPSK modulation operate alongside QAM. This is to enable the system to dynamically adjust to link conditions and requirements such as signal level, noise, the data rate required, and so on.

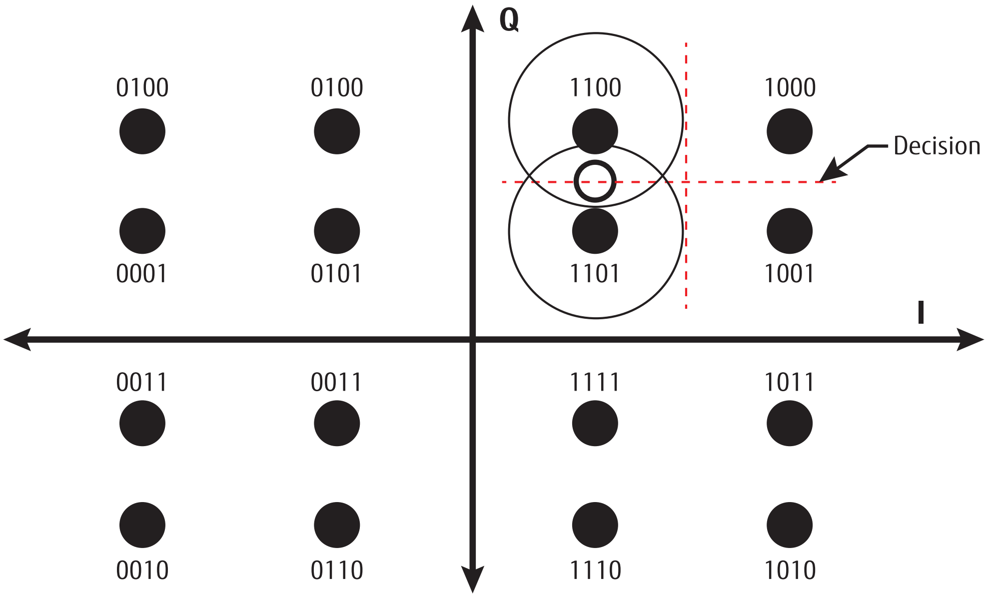

Figure 1: 16-point QAM constellation points with associated bit-mapping and decision boundary

When using QAM as depicted in Figure 1, the constellation points are normally arranged in a square grid with equal vertical and horizontal spacing. As a result most common forms of QAM use constellations with the number of points equal to a power of 2, i.e. 2, 4, 8, 16, and so on.

By using higher order modulation formats, i.e. more points on the constellation, it is possible to transmit at a very high data rate. However, as the points get closer together, they are more susceptible to noise and data transmission errors.

In Figure 1, a 4-bit per symbol representation is shown with 16-point QAM. Each point represents the four bits shown around each dot. On the IQ chart, each point can be represented as follows:

$I = A\cos(\phi)$ and $Q = A\sin(\phi)$ where A = amplitude and ϕ = phase

Using the expression $A\cos(2\pi ft+\phi)$ for the carrier signal I_c.

The carrier signal can be represented as follows:

$$I_c = A\cos(2\pi ft+\phi) = I\cos(2\pi ft) + Q\sin(2\pi ft)$$

This expression shows that the resulting waveform is a periodic signal where the phase can be adjusted by changing the amplitude of either or both I and Q.

In conventional modulation techniques, the expression for this carrier signal translates into the use of coder, decoder, modulator, demodulator, oscillators, mixers, de-mixers, multiplexers, de-multiplexers and filter modules as data is transmitted and received. These various transmitter and receiver modules in the up-and-down conversion path introduce transmit-receive delays that contribute to overall higher latency.

Impulse Radio Transmission

The transmission method used by IR technology is in sharp contrast to conventional QAM modulation. In IR transmission, impulse signals corresponding to input bits are transmitted by ultra-short pulses. The pulses are wideband-amplified and filtered to extract the transmitted E-band spectrum corresponding to the input signals. On the receive path, an innovative wideband low-noise and low-distortion envelope detector extracts the originally transmitted data at the remote site. The IR transmit and receive path therefore translates into the use of simple pulse generator, wideband amplifiers, wideband filters, and energy envelope detector modules.

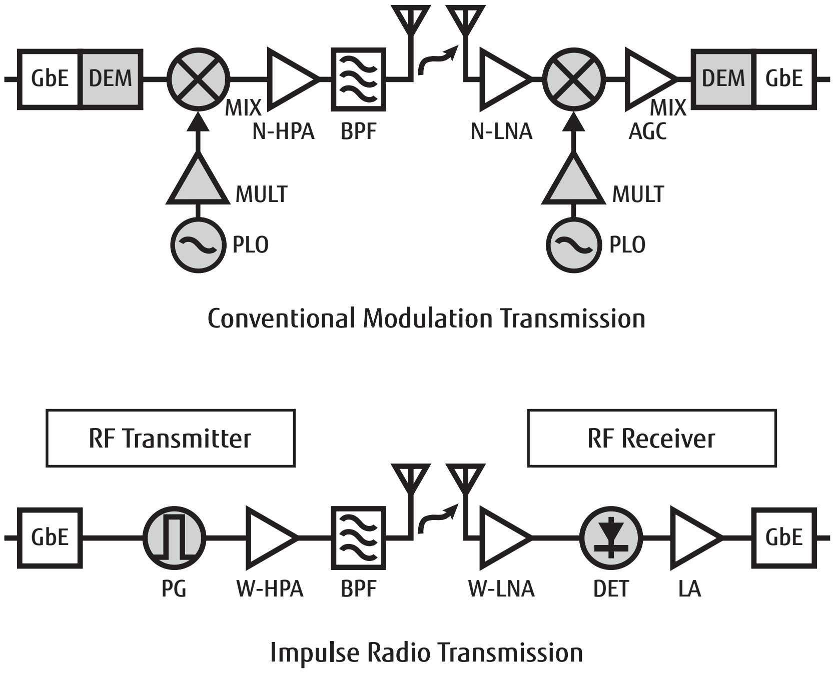

Figure 2: Difference between conventional modulation and IR transmission

Figure 2 depicts the differences between the conventional data transmission that uses an up-and-down converter for QAM (top) and IR transmission that uses ultra-short pulses (bottom). The IR transmission method completely eliminates the need for an up-and-down converter and the multiple parts it consists of, namely a modulator (MOD), demodulator (DEM), oscillator (PLO), multiplier (MULT) and mixer (MIX). Eliminating all these parts results in a simple configuration that facilitates small form factor, low power consumption and low latency [1].

In the frequency domain, IR transmission results in infinite bandwidth. Innovative IR technology has been harnessed to derive a wideband front-end needed for future growth to serve the needs of a high-capacity multi-radio environment.

A millimeter wave-based technology employing bidirectional "pencil-like beam" signal characteristics is used to transmit and extract E-Band wave packets from the frequency domain while eliminating spurious emission and keeping distortions very low (minimal interference).

Limitations of Conventional QAM In Comparison to IR

Although QAM appears to increase the efficiency of transmission for radio communication systems by utilizing both amplitude and phase variations, it has a number of drawbacks in comparison to IR transmission.

Noise Susceptibility

Conventional QAM transmission systems are susceptible to system and atmospheric noise. This is because, in the case of high data transmission rates, the constellation points in Figure 1 get denser and closer together. Only a low level of system or atmospheric noise is needed to move the signal point to a different decision point by a decoder. In addition, with increased system noise, the constellation points become bigger "blobs," making the decoders more error-prone. For example in Figure 1, a receive bit pattern in one of the blobs can either be decoded as 1100 or 1101 around the decision boundary. Higher order QAM modulation schemes are considerably less resilient to noise and interference. In contrast, IR transmission is resistant to distortion and interference because of multipath immunity and low-power spectral density. IR is also less susceptible to atmospheric attenuation.

Hidden Data Rate Challenges

While it is possible to transmit more bits per symbol with QAM, if the energy of the constellation is to remain the same, the points on the constellation must be closer together, causing data transmission to become more susceptible to noise, as depicted in Figure 1. This results in a higher bit error rate than for the lower order QAM variants. In this way, the balance between achieving higher data rates and maintaining an acceptable bit error rate must always be carefully monitored in any radio communications system. By contrast, IR is less susceptible to data transmission noise at higher data rates.

Amplifier Linearity

When using QAM with an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, making them less attractive for mobile data applications. IR on the other hand extracts low-distortion E-band wave packets from components spread over the frequency domain [1].

Component Complexity

Based on the transmitter and receiver design for conventional QAM modulation techniques, the analog and digital components needed are specialized along the up-and-down conversion chain.

QAM is a complex signal that requires specialized modulators and demodulators for practical data transmission. Any nonlinearity will alter both the relative levels of the signals and the phase difference, thereby distorting the signal and introducing the possibility of data errors.

In addition, conventional modulation systems are designed to support a dynamic adaptive modulation technique that senses the channel conditions and adapts the modulation scheme to obtain the highest data rate for the given conditions. IR is less complex with the elimination of the up-and-down conversion chain.

Latency

Conventional QAM modulation introduces transmit-receive delays that contribute to overall higher latency, on account of the design of the transmitter and receiver modules in the up-and-down conversion path. With its relatively small buffer requirement, IR is designed to have exceptionally low latency (<20 μsec one-way), far lower than the delay budget of most critical data transport applications.

Benefits of IR Transmission

Beyond the comparative limitations of QAM technology, IR offers additional benefits when compared to conventional modulation methods:

Low Power

IR technology benefits from the reduction in complexity associated with eliminating the up-and-down converter of conventional QAM. The reduced complexity results in lower power requirements, which helps to support use of alternative power sources such as solar and battery.

High Data Rates and MultiRadio Support

IR technology supports a wideband front-end, which is very attractive for advanced high-capacity radio transmission capable of supporting a multi-sector, multi-radio and multi-standards environment within a compact E-band radio module. In addition, when compared to the conventional QAM modulation, IR supports multi-gigabit throughput with low distortion.

Conclusion

The widely used QAM method appears to increase transmission efficiency for radio-based communication systems, but the more innovative IR technology offers significant benefits, including compactness, low power consumption, and low latency.

The lightweight and compact form-factor of IR technology allows for ease of deployment and operation in multiple scenarios. IR technology by design is invariably low on power consumption, allowing use of alternative or renewable power sources, such as solar technology. IR technology also has very low latency to meet the stringent requirements in many data transport applications, making it a highly attractive alternative to fiber.

IR technology offers new opportunities to network operators and service providers, enabling them to expand their networks with the additional benefit of low cost, ease of deployment and low power usage, while supporting advanced low-latency applications such as CPRI fronthaul with high reliability.

References

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