# **Adaptive Coding and Modulation for Phase 4 Ground**

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**Coding and Modulation Basics**

In analog wireless communications, continuous signals are sent from transmitter to receiver. Voice, for example, is directly encoded in analog signals by a proportional relationship. The changes in audio that make intelligible speech are proportional to changes in either the frequency (FM), amplitude (AM), or phase (PM) of a transmitted signal.

In digital wireless communications, data such as voice is represented by the digital symbols 1 and 0. Coding is the process of adding the right type of redundancy. When we talk about **code rate**, we are talking about the ratio of how many bits go in to the coder over how many go out. A rate 2/3 code takes in two bits and produces three. The extra bit is produced with mathematics especially designed to make the signal more durable as it travels from transmitter to receiver. The more bits you add, the smaller the ratio. Rates up to 1/9 can be found. This means that for every bit that goes into the encoder, nine come out. As you’d expect, the more coding, the more durable the transmitted bits are against noise and intereference. However, there’s a cost. If you compare two signals that are transmitted at the same rate, the one with more extra bits to protect it needs more time to get through. The data rate is lower.

After the data is coded into digital form the resulting bits are transmitted. The simplest type of digital waveform has two distinct states. One state corresponds to a 1, and the other state corresponds to a 0. Each of these ready-transmit-values is called a **symbol**. When we send one bit at a time, we have two symbols to choose from. An example of this type of modulation is Binary Phase Shift Keying (BPSK). The **modulation order** is the number of symbols we have to choose from. For BPSK it’s two.

This simple modulation scheme can be dramatically improved. Sending one bit at a time is a great start, but we can do a lot better. If we use four distinct states in our transmitted waveform, then we can send binary data two bits at a time. We now have four symbols instead of two. An example of this type of modulation is Quadrature Phase Shift Keying (QPSK). The modulation order has doubled to four.

How about 8? 16? 32? Yes to all, and more, all the way up to 256, 512, and even 1024. Sending 1024 bits in a single sample sounds amazing. So, why don’t we just send 1024 bits in a single sample all the time?

Engineering is all about trade-offs, and there’s another one right here. The higher the modulation order the more power required. This means that the signal carrier power for transmitting two bits at a time must be twice that of transmitting one bit at a time, assuming that we are transmitting at the same **symbol rate**. We pay for the doubling in information capacity by having to provide double the power. As long as you have enough power, you can use more powerful modulations. If you have too much noise or not enough power, then you have to drop down to a lower modulation order.

**Coding and Modulation Techniques in DVB**

Traditional communications design assigns a fixed **mod**ulation and forward error correction **cod**ing (MODCOD) to a link. The MODCOD is selected to provide reliable communications under worst case conditions. For example, a microwave link that points down off a mountain is often designed to be good enough to work through rain fade and summer foliage. During clear conditions in the fall with no leaves, plenty of excess link margin is available, but a fixed system designed to work through summer thunderstorms cannot take advantage of it. In the Digital Video Broadcasting (DVB) world, this technique is called Constant Coding and Modulation (CCM). Phase 4 Ground uses many DVB protocols and techniques due to their quality and widespread use in industry. Adapting these protocols to amateur radio is part of our mission.

Since it makes sense to adjust our link to better match observed conditions, one can design a system that uses a variety of MODCODs. An operator can then observe the link and then adjust the MODCOD to take advantage of better conditions. This technique is called Variable Coding and Modulation (VCM). VCM requires intervention of some sort to accomplish. In general, there is no feedback path from the receiver to the transmitter and a human is involved. But what if there was a feedback path from the receiver to the transmitter?

Adaptive Coding and Modulation (ACM) is a technique where the modulation and forward error correction are automatically changed in response to link conditions. As the link improves, higher order modulations and less coding allows increased throughput. Throughput can increase to take better advantage of available link margin. Challenging link conditions are responded to by lower order modulation and more coding. The throughput will decrease, but the link is maintained. The adaptation is enabled by establishing the set of MODCODs to be used, listing the metrics that control the decision to change MODCODs, and defining the algorithm that produces the decision.

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