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Datalink Access Options for T&E

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Suppose a new datalink needs to be developed for a test range. Datalink contractors come to discuss the design with the decision maker—in this example, a range engineer—and it becomes obvious that one of the key design decisions to be made is which network access scheme will be used. The range engineer is not exactly clear what network that should be, so he does some research. He begins the study by looking at the networks employed by the two major cellular providers, Cingular and Verizon. He talks with Cingular, and the company brags about its TDMA-based network. Verizon, on the other hand, tells him that its system is better because it exploits CDMA.

The abbreviations may be puzzling, but the range engineer finds out that both of these concepts refer to the way the cell signal accesses the network, commonly called media access control (MAC). He also finds out that there are other MAC techniques in common use, such as FDMA (radio stations) and CSMA-CD, which is used by WiFi. Why are there different MAC techniques; what are they exactly; and when is one chosen over another? The range engineer conducts some research to answer these questions.

To send a message over the airways, one would build a transmitter to broadcast a given radio frequency (RF) with a given power, using an antenna that has some spatial coverage pattern. The desired message is superimposed onto the RF signal by a technique referred to as “modulation.” (For digital messages, additional overhead data are provided, such as preamble, address and error detection/correction coding.) If one person were the only user of the airways in his region, there would be no reason to address MAC. However, this is almost never the case; that is, one must share the RF spectrum with other users. This is where MAC comes into play—it allows multiple users to simultaneously share the airways.

There are four domains that can be exploited to allow multiple users to communicate *without mutual*

interference. These are (1) frequency, (2) time, (3) space and (4) code.

■ Within the *frequency* domain, a dedicated frequency is assigned to a given user. Messages do not interfere with each other because they are broadcast on different, dedicated assigned frequencies. Television and radio are common examples of users of this technique, referred to as Frequency Division Multiple Access (FDMA).

■ Within the *time* domain, time is divided into slots that are assigned to, and employed by, each user. This is the way common conversation occurs; only a single speaker talks at a given time. The corresponding access control techniques are called Time Division Multiple Access (TDMA).

■ *Space*, in the sense of distance between users, can be exploited to allow users to communicate at the same time on the same frequency if they have enough spatial separation. A good example of this is frequency modulation (FM) stations broadcasting on the same frequency in different cities. This technique is referred to as Space Division Multiple Access (SDMA).

■ The *code* domain may be less familiar, but it is exploited in many applications to support multiple message broadcasts at the same time, in the same geographic region and on the same frequency. The Global Positioning System (GPS) is an excellent example of a user of this technique, referred to as Code Division Multiple Access (CDMA). CDMA superimposes (modulates) a code on top of the message. Each user has a unique code. These codes are specifically chosen to be “orthogonal,” which, in layman’s terms, means that if a receiver is “tuned” to the code corresponding to a given message, then that message is received and all the other messages are filtered out. Because CDMA codes are at a higher data rate than the information they carry, CDMA codes require more bandwidth than the messages do, thus spreading the bandwidth. For this reason,

CDMA is called spread spectrum coding. It is important to note that, as can be seen in *Figure 1*, this increase in utilized bandwidth is accompanied by a concomitant and directly proportional increase in the number of messages that can be broadcast.

All four of these techniques are appropriate for applications where there is a nearly continuous demand on the link, and the message must get through. For example, TDMA is typically used in test applications where time space position information (TSPI) is required by range safety on a periodic basis. But is this the best choice?

There are other MAC techniques, but they can result in *mutual interference*. Carrier Sense Multiple Access (CSMA) is normally used in applications where the data broadcast demands occur in bursts. For example, CSMA is used in training applications when a weapon launch puts an instantaneous high demand

on the link. This demand remains throughout the weapon fly-out and then drops suddenly following target destruct/miss. These “bursty” MAC techniques are excellent at meeting instantaneous link demands but suffer from mutual interference as traffic loads increase. So at this point, one can stop investigating CSMA because the test and evaluation (T&E) application requires interference-free communication.

As the user continues research into interference-free MAC techniques, he discovers that, for a given geographical area, there is a maximum interference-free capacity that can be achieved, regardless of the access technique used. FDMA, CDMA and TDMA attempt to allocate this available capacity to ensure that there is no mutual interference. The sampling theorem states that, for a total (double-sided) bandwidth W and a duration T , there are only WT degrees-of-freedom, or number signals that can be broadcast without interfer-

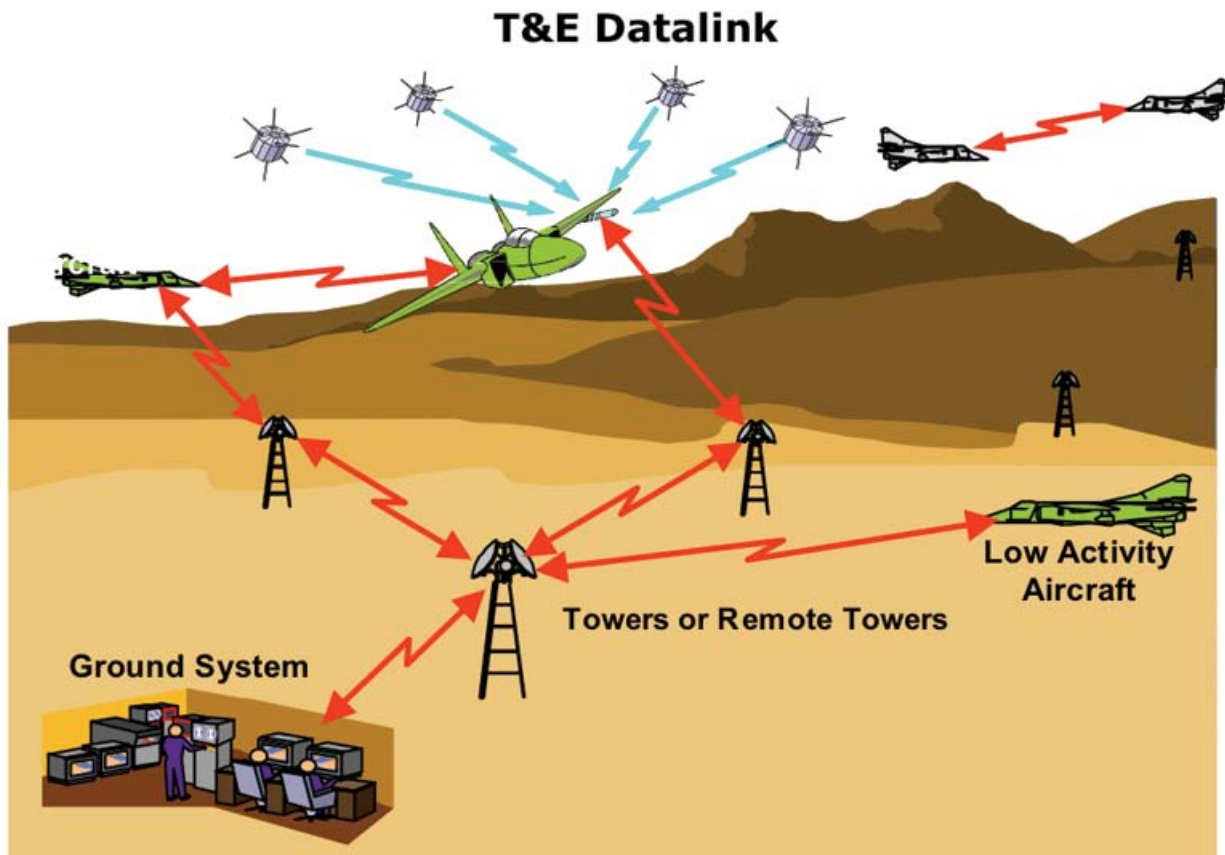


Figure 1. T&E datalink

ence. How will each of the modulation schemes achieve this optimum number of broadcast signals?

As an example, suppose a user wants to transmit 10 total signals of duration T across a given bandwidth W . An FDMA system could broadcast the 10 signals (of duration T) over 10 channels, each of bandwidth $0.1 W$; whereas, a CDMA system would be able to broadcast 10 orthogonal signals, each of the signals employing W , the total bandwidth. A TDMA-based network, on the other hand, could break the duration, T , into slots. For example, if T were assigned to five users, each user could broadcast for the duration, $0.2 T$. Because the time duration, T , was reduced by a factor of five, the broadcast bandwidth must be increased by a factor of five (from $0.1 W$ to a bandwidth of $0.5 W$) to preserve signal quality. This five-time slot, two-channel TDMA scheme would support 10 signals. *In each case, only 10 signals can be broadcast interference-free, that is, 10 degrees-of-freedom.* Then, if the maximum capacity is the same, what is the advantage of one access scheme over another? One must keep digging.

In the range engineer's range application, he wants all of his users to be on a single network. This is most easily implemented by employing either two frequencies, one for downlink and one for uplink, or a single frequency for both uplink and downlink communication. The single frequency is preferred because the transceiver is less complex (that is, less expensive), and a single frequency allows any user to hear both uplink and downlink communications. So FDMA is out. His investigation turns to CDMA.

The range engineer finds out that CDMA provides multipath rejection and increased protection against jamming when compared to FDMA and TDMA. In addition, he learns that there are applications where it has capacity advantages, as the following example illustrates. Imagine (at some instance in time) that there are 20 users and 10 available frequency channels (each of bandwidth $0.1 W$) with a single frequency assigned to each user. In this case, if 10 users try to talk simultaneously, then it is very likely two of the users would be on the same frequency. If this happens, there would either be significant interference or channel access denial, that is, circuit busy. If, on the other hand, each of the 20 users has a unique CDMA code (with a bandwidth of W), requiring that the total bandwidth of the 10 channels (W) be assigned to each user, then any 10 users could communicate simultaneously without any inter-

ference. In fact, if an additional CDMA user were to join the net, there would be interference, but communication quality would likely remain good; although at some point, as more users join the net, communication quality would become unacceptable.

This ability to support more than WT degrees-of-freedom on a CDMA net is called "soft capacity." This is the power of CDMA: For applications where there are more users than channel assignments and when the usage is random, CDMA may be a superior access technology. The range engineer realizes this is the primary reason that Verizon employs CDMA. However, this is not the range engineer's T&E application, because he has a finite number of users, each of whom needs to broadcast data periodically, and interference at any level needs to be avoided. So this CDMA capacity feature cannot be exploited for this application. Nonetheless, CDMA sounds promising because of its multipath and anti-jam properties. Upon further digging, however, he finds out that CDMA is complex to implement. For CDMA to work, all simultaneous signals input to a receiver must have approximately the same signal level (for unwanted signal rejection to occur). For this T&E application, the received power will vary greatly because the transceivers are scattered at varying locations about the test range. This requires the implementation of dynamic power control to achieve signal-level equality. The complexity of dynamic power control makes CDMA a poor choice for T&E applications.

So this brings the range engineer to TDMA. TDMA, as the name implies, is a natural choice for the periodic messaging required by the T&E application. Although it has none of the multipath and anti-jam properties of CDMA, it does provide network flexibility in that time slots can be dynamically assigned and reassigned. But the real advantage of TDMA is that it is very simple to implement. Timing must be maintained, but this can readily be provided by an onboard GPS.

The range engineer has come to the end of his study, and he has learned that there are a number of network access schemes. The selection of one over another (or some hybrid combination) depends on the requirements of his application; but for his T&E datalink, more times than not, TDMA is the way to go. □

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