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*Wireless Technology
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ASSOCIATION FEATURES

Annual Directory of ITEA Corporate Member Capabilities, 2007

FEATURED CAPABILITY

The Atacama Large Millimeter/Submillimeter Array (ALMA), Chajnantor Valley, Chile

TECHNICAL PAPER ABSTRACTS:

The Radio Spectrum—A Critical Resource for T&E

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The radio spectrum is a critical resource for a large percentage of test and evaluation (T&E) endeavors and for the development programs for which the T&E is conducted. This has been true for military weapon systems at least since 1912 when radios began to be used in airplanes. For many years, the development and test communities used the radio spectrum with little concern about availability or access. The invention of solid-state electronics and the emergence of the "Moore's Law" phenomenon changed all that. The combination of explosive growth in commercial spectrum consumption and solid-state electronics capabilities has moved spectrum access for T&E to the top of the list of threats facing the ability to test weapon systems adequately. The challenges of maintaining adequate radio spectrum are not limited to the test community; the entire U.S. Department of Defense is struggling with the changing world of electromagnetic spectrum usage. This article addresses the challenges of ensuring adequate spectrum for T&E and proposes treating spectrum as cost elements in the acquisition and sustainment life cycles of programs. This article also describes methods to increase the probability that the radio spectrum does not become a barrier to adequate testing and that the system under test will have the electromagnetic performance needed to accomplish its intended mission.

Wireless Technology Applications InterTEC-Based T&E of Network Centric Operations: Current State & Challenges Ahead

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Joint network-centric operations and the related warfare systems fostering transformation are increasingly employing wireless technologies to meet the mandate of the Office of the Secretary of Defense (OSD) that all Services become information-based with lighter force structures supporting missions that utilize joint capabilities. With the Global Information Grid on the horizon, systems producing and consuming tactical, operational and strategic information are increasing the need for ubiquitous network connectivity with a corresponding increase in the amount of wireless information flow, especially for systems that operate at the "tactical edge" of the battlespace. The test community is being asked to develop innovative approaches to both test the application of wireless communication in the joint battlespace, and to employ wireless technology in the application of testing. The Services and OSD are investing in a number of initiatives to meet this challenge. This article describes the OSD Interoperability Test and Evaluation Capability (InterTEC) project's current use of wireless technology to implement a joint interoperability test capability in a distributed Live-Virtual-Constructive environment, the projected T&E wireless capabilities required to support tomorrow's testing of system-of-systems, and the associated technology gaps that need to be addressed.

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Wideband Location Positioning System (WLPS) for a GPS-Denied Environment

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In recent years, test and evaluation (T&E) in Military Operations on Urbanized Terrain (MOUT) facilities has received increased attention due to the emphasis on improving the ability to conduct urban warfare. Support of Future Force warrior T&E of components and systems will require accurate time space position information (TSPI). Although the Global Positioning System has revolutionized T&E by easily providing accurate TSPI in open environments, it is inadequate for urban and indoor environments, so an alternative method for obtaining TSPI in MOUT test sites is needed. The Georgia Tech Research Institute has pursued development of the Wideband Location Positioning System, which will lead to a small, low-power receiver that can be embedded in a system under test (SUT) to capture TSPI data for T&E. The development is based on the use of long pseudo random noise sequences with chip durations of 546 picoseconds, yielding native resolutions of 0.16 meters. This system will be configured with a completely passive receiver, as well as transmitters that are fixed at known locations around the SUT. This system will be effective when the SUT is behind walls or inside structures, and the position of the SUT will be determined in the after-action review.

A New Vector for Developmental Test and Evaluation (DT&E)

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The Department of Defense (DoD) has a mandate for a simplified and streamlined acquisition system. Reports from the Quadrennial Defense Review and National Research Council, among others, have triggered a transformation for DoD acquisition that portends five specific imperatives for the developmental test and evaluation (DT&E) community: (1) DoD must field improved defense weapon systems capabilities more quickly to the warfighter; (2) Immature technology is a primary cause of weapon systems fielding late and over cost; (3) DoD must revitalize its test and evaluation (T&E) workforce education programs and must train incoming professionals as the aging workforce retires; (4) Efficient and effective distributed, live-virtual-constructive synthetic environments are essential to support developing and testing interoperable systems for joint capabilities; and (5) Acquisition policy, guidance, practices and procedures must enable more effective DT&E for streamlined acquisition.

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Mobile and Ad Hoc Wireless Networks (MANET) for Use in Test and Evaluation

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The test and evaluation (T&E) of weapons and materiel for warfighters requires the measuring and reporting of performance data. These data are typically acquired using remote data acquisition methods, because these systems are tested in harsh or dangerous environments. Telemetry standards have been established and have been the technology of choice for the T&E community. Many T&E scenarios now closely replicate realistic warfighting environments, where data are produced at unspecified times and where multiple test articles are on the move to sites where infrastructures for data acquisition are not possible. In addition, these data, along with range command and control information, are often exchanged bi-directionally, where spectral limitations may require the use of only a half-duplex single channel. These T&E attributes can be accommodated by what is typically defined as MANET: mobile and ad hoc wireless networks.

Data Considerations for Testing Networked Systems

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Consideration for operational test data collection in a network-centric environment requires early access to the system under test and access to developmental technical data from the program manager and developmental tester. The purpose of this article is to outline some of the challenges associated with collecting data in a network-centric environment, such as the Joint Network Node–Network (JNN-N). The JNN-N is a state-of-art transport system that provides reliable, high-speed information services and information exchanges to provide the warfighter with the means to control battlefield tempo by getting information to the right place at the right time.

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A Cautionary Tale on Testing and Evaluating Tactical Wireless Mobile Ad Hoc Networks

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Transformation dictates that the nature of future warfare will be network-centric where net-centricity is contingent on a ubiquitous network. At issue are the capabilities that this network must have to make network-centric operations (NCO) possible. Wireline and commercial wireless technologies have colored the expectations of what is possible and, in many cases, the requirements for the network and the applications as well. This article argues that these technologies are fundamentally different than what is required on the battlefield and, if caution is not exercised, these technologies could easily misdirect requirements and subsequent testing and evaluation strategies toward performance measures that are orthogonal to those required to enable NCO. The article reviews several contemporary discussions of NCO and networks to arrive at the thesis that the critical networking technology for the tactical edge is one that allows users to communicate with each other locally regardless of their organization and without dependence on connectivity to a network infrastructure. This article suggests test and evaluation approaches to validate this capability and to measure its effectiveness.

Wireless Network Modeling & Simulation in Support of Training, Testing & Range Instrumentation

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In recent years, range digitization efforts have been undertaken to upgrade the strategic telecommunication infrastructure of training and testing ranges. The goal is to provide the necessary communication bandwidth and state-of-the-art technology to support the ever-increasing demands in high-speed transmission of multimedia-range instrumentation data in real time. Meanwhile, recent years have also witnessed a tremendous growth of research and development in wireless communications and networking. To complement range digitization efforts, while fully benefiting from recent technological advancements in wireless communications, there is a need to develop broadband wireless networks for seamless integration with existing "hardwire" range communication networks. This article considers the modeling and simulation of a hybrid wireless/optical network for range communications using the hybrid network OPNET. OPNET consists of a wireless local area network (WLAN)-based broadband network and a SONET-based infrastructure network. This article discusses several relevant issues, such as wireless extension of a SONET network and WLAN AP node modeling. Simulation results and wireless link performance analysis (for example, throughput and delay) are presented for the proposed hybrid network for range communications.

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PRESIDENT'S CORNER

I hope this note finds each of you and your families well. The holidays are behind us, and it is time to get back to work! As I mentioned in the last *ITEA Journal*, I want to use this column as a source of ITEA news and to provide a venue for presenting my views on issues that impact the test and evaluation (T&E) community. I will postpone ITEA news until the next issue of the *Journal* because I want to focus on an investment strategy whose time has come; that is, test and training interoperability.

Improved interoperability between the test and training communities is an oft-stated goal of senior leadership within the Department of Defense (DoD). This goal is driven by the desire to lower the cost of expensive test and training instrumentation systems and to make better use of the existing test and training ranges. Senior leaders also are influenced by the similarities in the functions provided by test and training instrumentation. For example, both test and training use nearly identical instrumentation pods to provide time space position information (TSPI). These pods provide similar functionality and may even be produced by the same vendor. Hypothetically, the question is posed, "Why can't these pods be similar, or at least interoperable?" The answer is, they can, and it is time we commit to making this happen.

For too many years, DoD has focused on test and training differences. Test scenarios are stereotyped as scripted, high-precision, high-data-rate, few-on-few missions. Training scenarios, on the other hand, are described as free-play, moderate-precision, low-data-rate, many-on-many missions. And yes, they are funded differently, which could be argued complicates joint developments and the participation in joint exercises. That being said, are these differences the real reasons that we do not share developments? The answer is no: Similar instrumentation can support both test and training scenarios. Lack of interoperability is due to a "not invented here" mentality and the lack of tri-Service commitments within DoD. History has taught us that, although testers typically develop the advanced technology, trainers *do* adopt the same technology, but some time later. In fact, test and training instrumentation is remarkably similar, only it is used differently. If interoperable instrumentation were developed from the "get go," trainers would benefit from the test community investment in technology, while the testers would benefit from economy of scale (that is, trainers buy a lot more instrumentation than testers do).

Times they are a changing.... DoD sees the cost-benefits that interoperability offers. In September 2006, a "Test and Training Interdependency Initiative" memorandum was issued. It was signed by the Under Secretary of Defense for Acquisition, Technology and Logistics, the Under Secretary of Defense for Personnel and Readiness, and the Director, Operational Test and Evaluation. This memorandum states that, "The test and training communities require similar capabilities to support their respective missions. Many of these capabilities have been developed separately by each community without exploring the potential for common, modular or interoperable solutions. We seek your support in seeking an interdependent approach to minimize fiscal outlays and achieve test/training mission synergies." These test and training leaders propose that a corporate investment be applied to overlapping functional areas. These areas include airborne instrumentation; live, virtual and constructive test and training environments; and multi-level security.


Thomas J. Macdonald

This change is now timely because open architecture designs such as PC-104, standard interfaces such as the Test and Training Enabling Architecture (TENA), miniaturized technology and common acceptable technologies (for example, wideband wireless Internet and the Global Positioning System) are *pulling* us to be interoperable. At the same time, fiscal constraints are *pushing* us to develop interoperable systems.

It is time for the test and training communities to set aside their parochial interests and begin the journey toward interoperable instrumentation. What level of interoperability should we strive for? Should it be true commonality, which would call for the use of identical hardware and software; modularity and composability, where common building blocks are shared; or simple co-existence, where our systems simply do not interfere with each other? The optimal end-state for any scenario will depend on the economics of the particular situation. But one thing is certain: We can no longer rationalize the cost of independently developing similar instrumentation. Join me in the interoperability journey.

Beginning with this first *ITEA Journal* issue of 2007, we introduce a new column—"Inside the Beltway." It will present topics of choice from the OSD T&E leadership. While the *Journal* is not a DoD policy medium, neither should it be devoid of policy developments affecting T&E. For this reason, readers may on occasion note certain DoD policy implications in this feature. We look forward to regular contributions by senior leaders from DOT&E, OUSD(AT&L) and DDT&E. We welcome Dr. Ernest Seglie, DOT&E, who initiates the "Inside the Beltway" column.

Your comments are welcomed and encouraged. Please e-mail me at: **comments@itea.org**

T&E at the Intersection of Internet and Wireless Resources

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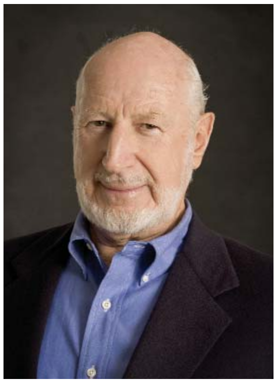
The use of wireless resources for the implementation of network-centric warfare (NCW) provides a new set of challenges in the testing and evaluation of key elements of the Global Information Grid (GIG). Network-centric test and evaluation (T&E) requires a broader view of the measurement process basic to the effective use of wireless resources within the GIG in order to accomplish the mission objectives of the GIG.

Many of the common protocols used to package user information for the Internet within the commercial sector have been designed for transmission channels limited by server latency, switching congestion or network survivability considerations. Indeed, the origins of TCP/IP (transmission control protocol/Internet protocol) may be found in the Defense Advanced Research Projects Agency (DARPA)-sponsored and defense-motivated ARPANET of the 1970s. Commonly used higher-level protocols within the Internet such as HTTP and SMTP/POP/IMAP developed in both the military and civilian sectors in the 1970s and 1980s seem to have been designed for transmission within a backbone structure not seriously limited by bandwidth transmission constraints.


Dr. Norman Abramson

In many of today's applications, as well as in the GIG, the edge of the network providing access to the user has assumed an increased level of importance in the achievement of fundamental mission objectives. And wireless access at the edge, limited by availability of usable spectrum and transmitter power, is emerging as a serious bottleneck in a network-centric environment. Conventional measurements used for T&E may not disclose this bottleneck.

If wireless access at the edge is provided by a wireless channel dedicated to a single transmitter, then wireless access can operate with the same efficiency and effectiveness as wired access, as long as enough spectrum is available to provide a separate channel to each transmitter with the data rate required by the application. However, there is increasing evidence showing that sufficient spectrum to operate on the basis of a single channel dedicated to each transmitter may not be practical for the NCW scenario.

If wireless access at the edge for bursty information sources is provided by a shared random access channel, providing network access to multiple transmitters, then the spectrum required may be decreased by two orders of magnitude or more. However, in this case, the connectivity and information needs of a reasonable set of disparate platforms at the edge of the network can be smothered by the protocol overhead and structure of the network itself. The problem is that, in both commercial off-the-shelf (COTS) network systems and in specialized networks, the awkward interaction of the channel sharing process with HTTP/TCP/IP and other more specialized high-level protocols can limit the effectiveness of both TCP and random access within the network.

Conventional measurements of network performance have focused on the ability of the network to transmit *traffic* rather than *information.* The key distinction here is that the information transmitted in a network can be defined as the network product destined for the end user of the network, while the *traffic* transmitted in a network can be defined as that information together with the overhead inserted by various levels of protocol for the smooth functioning of the network. When the network information comprises at least *50 percent* of the network traffic, there may be room for improving the network's performance, but the measurements necessary for effective T&E of the network are usually clear. However, in certain common Internet applications, the network information may comprise *0.1 percent* or less of the network traffic so that, to the extent that these Internet protocols or protocols based upon them are utilized in NCW, conventional measurements can obscure the key data required for effective T&E of the network.

A specific example may help to illustrate this issue. Consider the transmission of network information and of network traffic in the access channel from the user at the edge of the network to a Web server. The amount of traffic generated by a single click using Microsoft's Internet Explorer on a common Web site, "yahoo.com," has been measured. In this case, a single click on an arbitrary selection on the Web page generated a total of *84 packets* and *21,180 bytes* of traffic from the user to the Web server. Even more traffic is generated from the network to the user in response to this click, but the network bottleneck in these wireless situations providing network access is almost always the channel from the user to the network.

The generation of *84 packets* and *21,180 bytes* in the access channel in response to a single user click certainly sounds excessive, so the question becomes, "How many packets and bytes are really necessary to transmit the single user click?" Because there are fewer than 256 places to click on this Web page (and on almost *all* Web pages), the amount of information needed is just 1 byte. Of course, there is a certain amount of irreducible protocol address and control information needed as well, but if the user is at the network edge, then 4 bytes of this overhead in the wireless access channel can do the job, and the user can say that about 5 bytes are needed to specify a single click to a Web server. There is no great precision in this number and, if the user has to type out additional information for the browser, the number of bytes will increase, but there is no need for precision to make the point of interest here.

The efficiency of the access channel in this example is just *5* divided by *21,184,* or about *0.024 percent*. Putting this another way, out of every *4,000 bytes* transmitted in the key network bottleneck, the random access channel, *3,999* are excessive protocol information bytes inserted into the network by the accretion of a legacy multiple level protocol structure. This protocol structure might make sense for the development and functioning of a network backbone where high-data-rate channels and switches are available because of other factors; but in a resource-limited, wireless, random-access channel, this level of bloated protocol traffic provides a barrier to exactly the kind of high-performance edge capabilities needed in today's and tomorrow's net-centric applications.

The use of scarce resources at the network edge to support a throughput efficiency of less than *0.1 percent* in the wireless random access channel will, of course, limit the amount of useful information from the wireless channel. But within the wireless random access structure, the penalty paid for this absurd level of network overhead involves more than just a major decrease in the throughput of the channel.

The overhead is inserted into the network for the purpose of providing a higher level of reliability for the delivery of information from a transmitter to a receiver. However, even the most cursory examination of the probability of successful transmission under a variety of telecom models makes it clear that, in the example used previously, the transmission of 84 long packets cannot be more reliable than the transmission of one short packet containing the information desired. A well-known first principle of medicine is *primum non nocere*—first do no harm. The same principle should be respected in the design of an appropriate set of protocols for the wireless random access channel.

The consequence of this level of protocol bloat is that a measurement plan for T&E must allow an evaluation of more than just the transmission of network traffic. To be of value in a network-centric environment with random access wireless capabilities, the measurement process must provide the foundation for an effective evaluation of both network traffic and network information at the edge of the network. And, if this measurement process can provide that foundation, it can provide a roadmap to the gradual removal of that protocol bloat as well. ❑

Dr. Norman Abramson, professor of electrical engineering emeritus at the University of Hawaii, is the recipient of the IEEE 2007 Alexander Graham Bell Medal for his work in ALOHA channels and wireless data networks. He received an A.B. in physics from Harvard, an M.A. in physics from UCLA and a Ph.D. in electrical engineering from Stanford. Before joining the University of Hawaii faculty, Dr. Abramson was associate professor of electrical engineering at Stanford University. At the University of Hawaii, he was a professor of electrical engineering and a professor of information and computer sciences. He served as the first chairman of the Information and Computer Sciences Department. He has taught courses in telecommunications and data networks at Berkeley, Harvard and the Massachusetts Institute of Technology on visiting appointments. He also has participated in research on data networks at the Institute for Defense Analyses and at the Defense Communications Engineering Center on visiting appointments. He was director of the ALOHA System at the University of Hawaii. He led the development and operation of the ALOHANET, which has been called the first modern data network. Among the innovations demonstrated in the ALOHANET were the first packet radio sensors, the first packet radio repeaters, the first satellite packet network (with Tohoku University, Sendai, Japan) and the first radio access to the Internet. ALOHA channels form the basis of the CSMA/CD protocols used in Ethernet, WiFi and WiMax. In addition, ALOHA channels are used as the control channel in all major digital cellular standards, including GSM and CDMA. Almost all existing two-way cable data networks utilize an ALOHA channel, while more than 90 percent of the nearly one million two-way VSATs in operation today use an ALOHA channel, either for the primary mode of data transport or for the control channel. Dr. Abramson holds six U.S. and international patents, including U.S. Patent 3,114,130, and U.S. Patent 3,163,848. The former is the first patent for the use of what are now known as CRC redundancy checks, the primary error control technique used today in digital communications and in disk memories. The latter is the first patent issued for the design of burst errors in digital systems. Dr Abramson is a Fellow of the IEEE and IEC, and is the recipient of the IEEE Sixth Region Achievement Award; PTC 20th Anniversary Award; IEEE Koji Kobayashi Computers and Communications Award; IEEE Information Theory Society Golden Jubilee Award; and Eduard Rhein Foundation Technology Award. E-mail: ***norm@hawaii.edu***

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 uses 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-

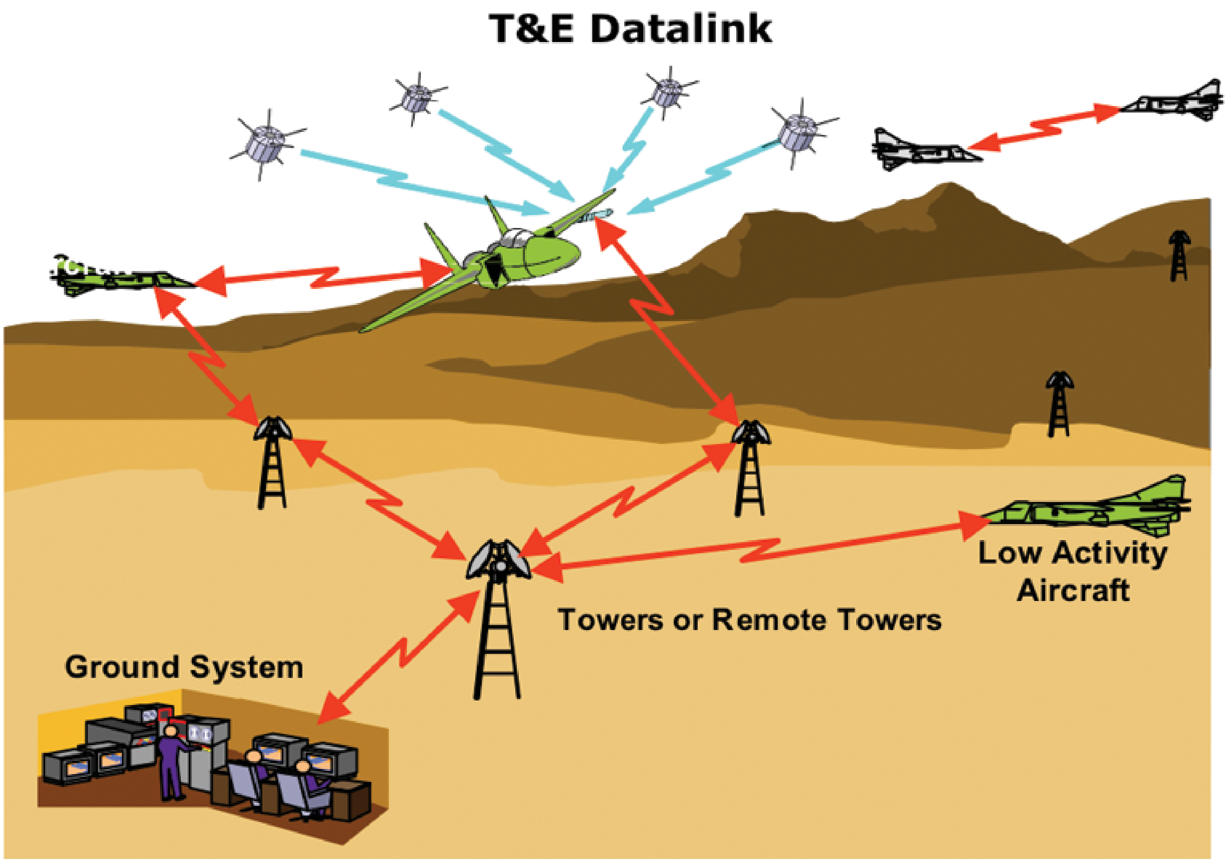

Figure 1. T&E datalink

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 interference. 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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