A Common Time Reference: Precise Time and Frequency for Military Systems

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The use of the Global Positioning System as the primary and most accurate means of disseminating time and frequency information has created an inherent vulnerability within some military systems. As a growing and diverse mix of military positioning, communications, sensing and data processing systems are using precise time and frequency from GPS, the precise accuracies required for their interoperability are becoming more stringent. Consequently, a new system architecture for providing a common time reference to the operating forces and their related subsystems is being developed. This architecture will provide a robust alternative to the former implementations of GPS as a time and frequency subsystem and mitigate the vulnerabilities of those systems to possible GPS countermeasures.

In this month's column, Ronald Beard and Joseph White describe their proposed common time reference approach and its relationship to present GPS time and frequency usage. They suggest a robust architecture comprising distributed time standards and precise time and frequency standards which reduces the sensitivities to GPS anomalies and lack of continuous contact. Utilization of existing resources and interconnection of these interoperable systems at the fundamental level of time and frequency generation will enable them to function together more effectively.

The Global Positioning System is enabling the transition to joint precision systems for navigation and positioning throughout the military. Less well-recognized is its role in providing precise time and frequency (PT&F) data for synchronization and communication. GPS has become the primary dissemination system for PT&F information for interoperability of naval and other Department of Defense (DoD) systems. The move toward joint, diverse, interoperating systems that can gather, process, and communicate raw data and place weapons on target through a continuous stream of information moving from sensors to weapons carriers requires a level of synchronization not possible before GPS. This flow of information requires mobile platforms in the field — whether on land, in the air, or at sea — to receive, maintain and distribute PT&F data previously only available at major timing centers. Consequently, GPS is evolving as a utility to disseminate a reference timescale and maintain it throughout the operating forces.

Many systems have existing PT&F standards that are being displaced by GPS timing receivers disciplining an internal oscillator. In general, these oscillators are of lower quality than the standards they are replacing. As the use of GPS-disciplined, lower-quality clocks and oscillators in-creases, so does the dependence upon GPS as the time source. To avoid proliferation of GPS receivers, the military is further distributing GPS-derived time signals to satisfy existing and new systems requirements. The signals are also being used to replace expensive clocks in some systems. Both of these situations are placing even greater dependence upon GPS and the need for continuous signal reception.

The increasing dependence on this utility is complicated by the vulnerability of GPS to electronic countermeasures. This vulnerability can be mitigated through the establishment of a common time reference (CTR) architecture using distributed time standards (DTS). This technique could provide an accuracy approaching that usually only found at timing centers. This complementary capability would decrease reliance upon GPS as a direct, continuous source of PT&F and provide a mechanism for jointly synchronizing the systems in the operating forces. This approach would require coordination and interchange of timing information between systems in a network-centric manner.

NETWORK-CENTRIC WARFARE

Network-centric warfare is a concept for operating diverse military forces in theater area operations. This concept calls for establishing interoperable systems across warfare areas, services, and weapons systems. Figure 1 illustrates this idea, showing joint forces and systems combined into a theater area operation, which requires the participating elements to interoperate on various centrally cooperative levels of movement, surveillance, offensive missions and defensive roles. Communications and data transfer will be central to cooperative interoperation.

An example of this interoperation is the need to dominate the airspace over the theater of operations. This requires the ability to completely and continuously detect, identify, and monitor all aircraft within the area. To accomplish this, all assets in the theater area force must be able to operate cooperatively and interactively. Data collection and transfer from the various sensors, platforms, and systems must be accurately referenced to common standards. For positioning, the common standard has become the World Geodetic System 1984. For the CTR, it is Coordinated Universal Time as maintained by the U.S. Naval Observatory, known as UTC (USNO).

SYSTEM TIME UTILIZATION

Military use of time and clocks can be categorized as follows:

Reference time for observations of platform positions or sensor measurements. This is time tagging, whose limits, in general, are determined by the dynamics of the particular system's motion.

Time interval for radio frequency or optical measurements. Position determination or radar measurements are prime uses, in which range measurements are obtained by multiplying an observed time interval by the speed of light.

Synchronization of communication signals, or data transfer links, ranges from local to global systems. Acquisition and demodulation of signal wave forms, bandwidths involved, and modulation rates and types determine time and timing requirements.

Data processing, the calculation of information and its transmission through processing nodes and networks, requires timing and clocks. Processing delays for the necessary calculations limit timing accuracy. Even asynchronous data transfer needs timing information.

Independent systems. Most DoD systems in use today were designed 10 to 20 years ago. Designing these systems and determining PT&F requirements — maintaining clocks remotely on board ships, for example — was very difficult. The precise time–dissemination techniques of the day offered limited coverage and capabilities. Consequently, most systems were designed around local synchronization and relative operation, and most of them operate independently of other systems. Absolute common time is necessary for worldwide operation, but its accuracy does not affect relative operation, and so is not a major operational issue.

Clocks and oscillators used in such system networks need precision in making time interval (frequency) measurements and need relative synchronization for short periods between local updates from other elements of the system. Quartz crystal oscillators, such as temperature-compensated crystal oscillators (TCXOs) and more stable ovenized crystal oscillators (OCXOs), are quite sufficient for these operating conditions. A net master controls synchronization within the system and thereby participation of the users in the network. User clock synchronization is monitored with communication signals and periodically updated, sometimes by a special synchronization preamble or system message. These messages typically update the time (or signal phase) difference of the clock in the user terminal and therefore keep it within the signal tracking or reception errors. Updating the time offset can introduce time steps in the user clock as a result of the way clock time is generated. Systems must be designed to handle such jumps.

Current time given by a clock, *T(t)*, is a function of the running time, *t*, since the clock was initialized as described by the clock equation:

$$T(t) = T_0 + R\,t + \frac{A}{2}t^2 + \int_0^t E(t')\,dt' + \varepsilon$$

T_0 is the initial time offset and is the term that is updated throughout the system by the master clock. Because of the rate, or frequency offset, *R*, the clock will continue to accumulate time at a different rate from the master. Rate aging, *A*, necessitates more frequent clock updates as the running time increases. Also, environmental effects, *E*, will integrate their effects over the duration of the clock's operation until it is recalibrated. The random noise component of performance, *e*, determines the precision and ultimate accuracy possible with the specific clock.

Referencing the relative network to a remote absolute time scale reference is difficult, inaccurate, and unnecessary for independent operation. The implementation of relative time within systems was an effective means of satisfying a particular system's mission. Few systems requirements give absolute time much emphasis. However, in operations such as forming a common air picture with other systems or multiple relative networks, the ability to synchronize between them and correlate data to an accurate common time becomes significant.

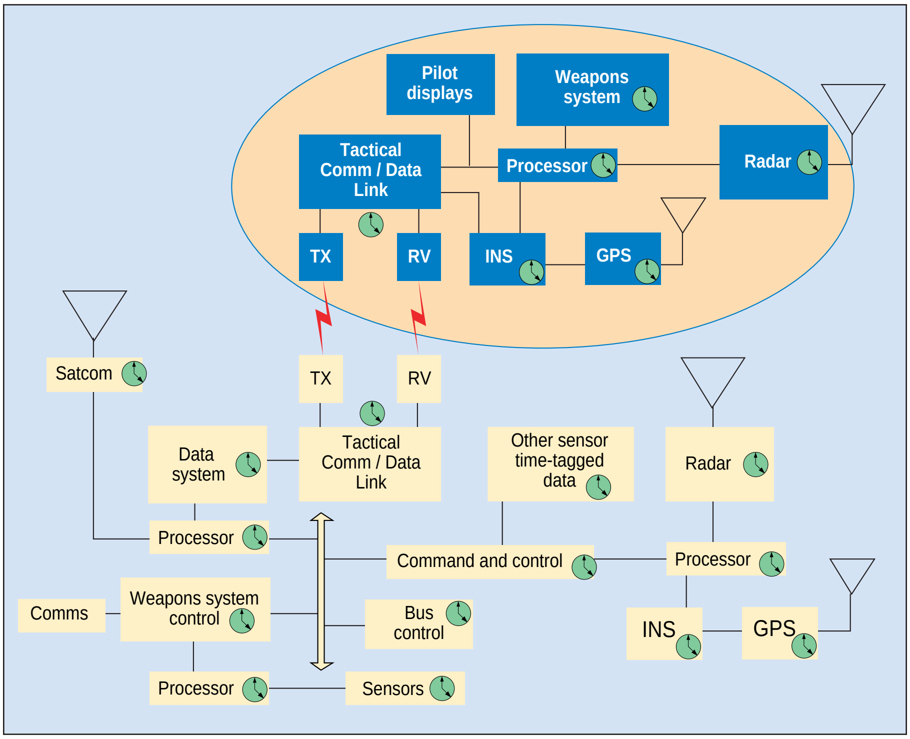

Figure 2 Virtually all electronic systems onboard ships and aircraft contain oscillators and clocks. Some of these systems need only relative time but intercommunication between systems requires time coordination.

Multiple systems. As military planners required systems to be more interactive and operate as part of a larger system or group of systems, the implementation of clocks within these systems became more difficult to clearly define. A generic ship and aircraft system is shown in Figure 2. The green clock symbols show some of the clocks contained in these systems, because virtually all electronic systems contain clocks and oscillators. The time requirements of the system depend not only on the clocks used, but on how they are used. Clocks within the system control the time of the system elements, but the manner in which they are applied controls the timing of the system. Even within systems on the same platform, the systems are predominantly organized as relative, self-contained systems. For example, a radar system and a weapons system may each employ their own internal time for operation. Moving data processed with one internal time to another determines the relations between the clocks and sets the timing paths. Accuracy limits are determined by instrument delays, uncalibrated delays (latencies) between units, and processing delays. Timing does not necessarily represent time of the system, but rather the arrangement of time use.

To achieve the required level of synchronization for network-centric warfare, a worldwide, highly accurate capability for time dissemination is required. GPS provides such a capability.

TIME DISSEMINATION VIA GPS

Various techniques for time dissemination are used within the scientific and timekeeping community, such as common view time transfer, which can compare clocks over intercontinental distances with nanosecond precision. The DoD user relies primarily upon passive time dissemination as a product of positioning and navigation, as illustrated in Figure 3.

This technique is made possible by the highly synchronous nature of GPS Time. GPS Time is continuously generated by the GPS Master Control Station Kalman filter at 15-minute intervals from the constant monitoring of the atomic clocks in the satellites and monitor stations. It is formed as a composite, or weighted average, of all these highly stable clocks. The offset and rate of GPS Time from UTC (USNO) is constantly monitored by USNO and included in the navigation message broadcast by each satellite. It enables the user to correct the GPS Time resulting from the navigation solution to give an accurate time in the UTC (USNO) time scale.

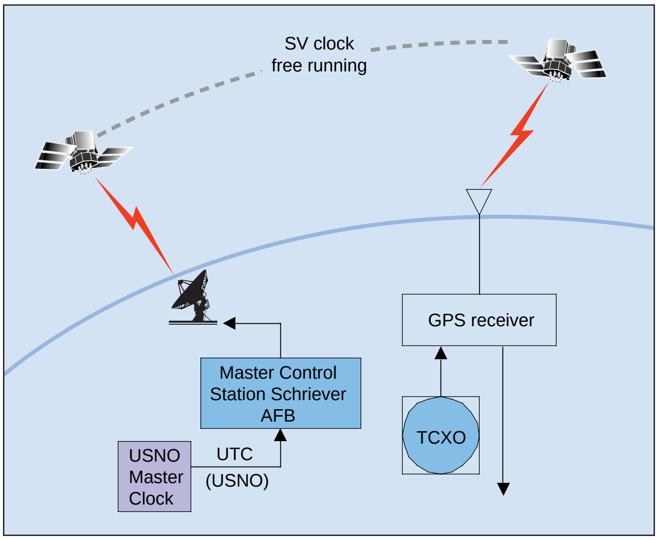

Figure 3 Time is disseminated to Department of Defense users primarily as a product of positioning and navigation.

The capability of the user to determine accurate time by this technique is highly dependent upon the receiver and instrumentation used, as well as the user platform dynamics.

The data shown in Figure 4 are the result of time dissemination testing at the Naval Research Laboratory with a Precise Positioning Service receiver in static positioning and time transfer mode. They are representative of the precision with which absolute UTC (USNO) time can be disseminated to passive receivers in field or mobile locations. With this technique, GPS can provide a common absolute reference time accurately across an operational theater to synchronize the variety of platforms and systems engaged.

GPS is so capable, and the instrumentation for civilian time applications has become so inexpensive, that small civilian receivers are being integrated into a variety of timing equipment, primarily for telecommunications, to

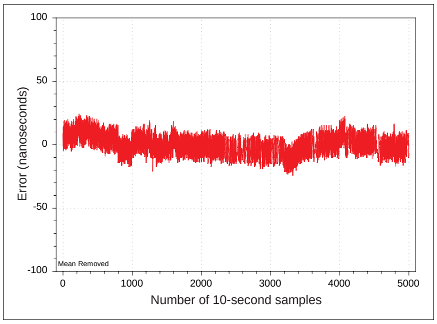

Figure 4 The GPS Precise Positioning Service can provide time transfer precisions (one standard deviation) better than 10 nanoseconds.

discipline clocks. These commercial integrated time subsystems with increased performance are being used to replace more expensive clocks and are available off the shelf. Newer telecommunication and data processing equipment for military systems, which now emphasize commercial best practices and off-the-shelf acquisition, sometimes contain these embedded GPS receivers, which introduce hidden vulnerabilities into these military systems. With UTC (USNO) time now accurately and generally available to systems and platforms worldwide, legacy systems designed around relative time concepts must be complemented with an effective overall architecture.

CTR ARCHITECTURE

Figure 5 shows an overall view of the generation, dissemination, and utilization of time. UTC (USNO) is the top element of absolute CTR and is established as the reference time for use with all U.S. military systems.

The primary time dissemination system (the second element) is GPS. Alternative time dissemination systems are now available that can supplement GPS both globally and locally. A new capability, known as two-way satellite time and frequency transfer (TWSTFT), has been developed, which makes use of communications satellites. TWSTFT can disseminate time with nanosecond accuracy globally, but the technique is a point-to-point capability, in contrast with the generally available broadcast capability of GPS. However, TWSTFT and the capability of tactical area relative systems, such as the Joint Tactical Information Distribution System (JTIDS), could be incorporated into the overall CTR architecture to develop an assured ability to disseminate the absolute CTR.

The final major block of the architecture contains the systems and their user infrastructure. The system–user infrastructure as shown in Figure 2 can be represented as a distribution of clocks and oscillators.

The distribution approach can satisfy many of the needs of the systems, because current methods tailor the accuracy and precision of the time supplied to match the system's requirements. It also meets the goal of reducing proliferation of GPS receivers by centralizing the capability. The disadvantage of this approach is that it will increase the dependence on GPS and any disruption or anomaly in GPS reception would be directly reflected in the time output to the systems. With the use of time links, which will be discussed later, the transfer would be a one-way time output over a point-to-point link. The time supplied must then either be directly accepted or means must be devised to evaluate the quality of the time input to support the decision whether or not to accept the time update. These time transfers usually also involve a time-offset correction as well, which could lead to time steps, as previously discussed.

The proposed CTR architecture approach is illustrated in Figure 6. Existing clocks already in place could be functionally incorporated into a combined clock group. The resulting group of clocks would then be combined with comparison, interfacing, and management equipment capable of maintaining an independent local CTR. This local CTR, shown by the blue markers, would be compared with the absolute CTR via the time dissemination element, which could consist of GPS receivers and other means, such as TWSTFT. Or, local CTR could be compared with absolute CTR and disseminated to task group participants by means of JTIDS. The dissemination systems, including alternatives, would be active participants in the composite time group maintaining time throughout the systems infrastructure and other task group elements.

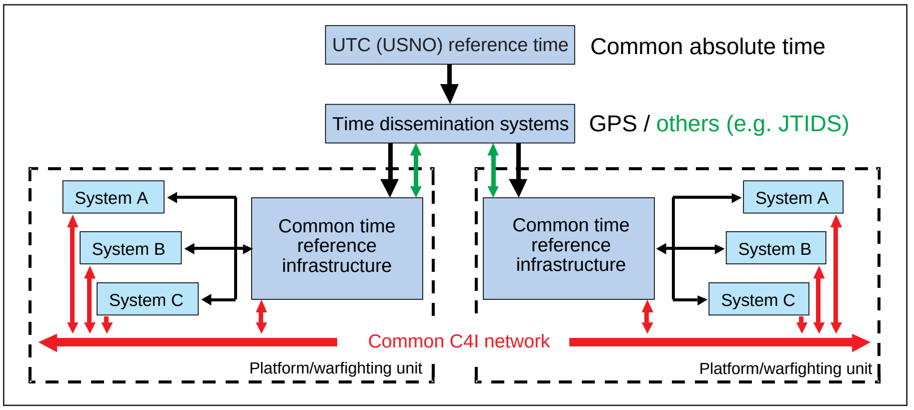

Figure 5 In the common time reference approach, time is disseminated from a central source through GPS and other means to platform warfighting units connected to a common command, control, communications, computers, and intelligence (C4I) network.

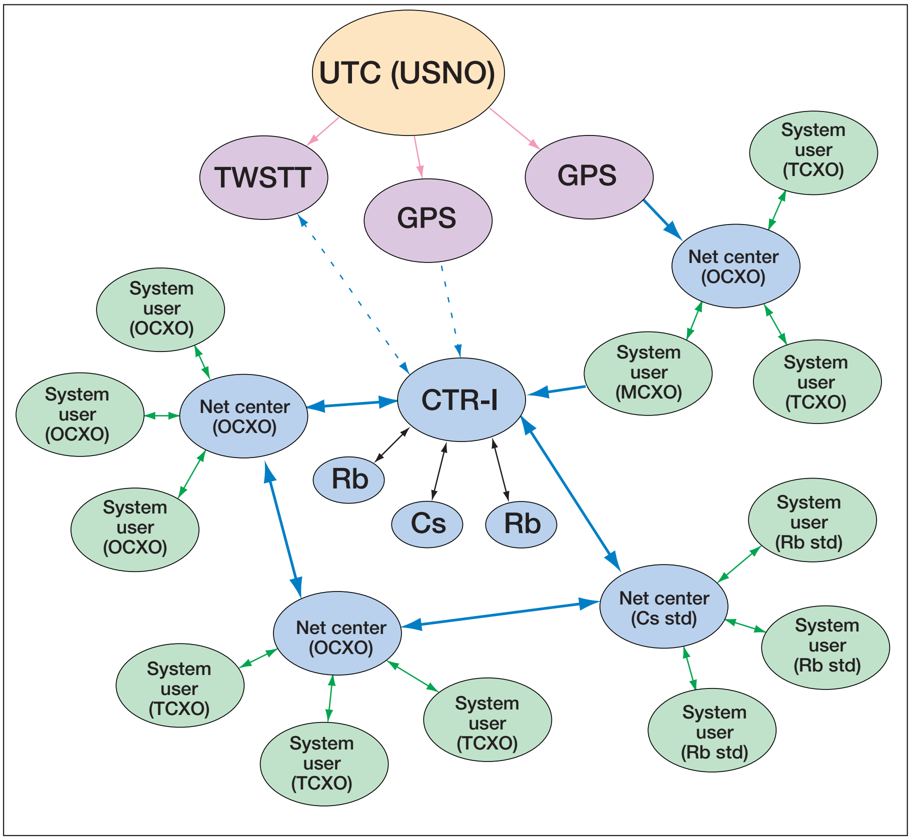

Figure 6 The common time reference (CTR) architecture would incorporate existing clocks into a combined clock group. Groups would be compared with an independent local CTR (CTR-I) which, in turn, would be compared with the absolute CTR through GPS and other means.

Figure 7 shows the elements of the architecture necessary for generation, comparison, maintenance, and distribution of the CTR within the platform and systems.

TIME DISSEMINATION INTERFACES

Central to this element of the CTR infrastructure are GPS receivers, which have been deployed on most naval ships and are being deployed on aircraft, with ground forces, in weapons, and at fixed sites of all services. Most of these receivers are intended for positioning and navigation purposes. Receivers just to support time also are in use, many of which, as discussed earlier, are embedded within system components.

An optimum interface or set of interfaces should be developed to provide an effective robust time interface that can interact with the primary dissemination system, GPS, and with possible alternatives. Prior efforts to establish a single standardized interface, such as the STANAG 4430, Precise Time and Frequency Interface for Military Electronics Systems, to replace the multiplicity of interfaces, have met with very limited success. How successful any new standard would be depends upon the extent to which the CTR architecture would be implemented. Nevertheless, a standardized interface in the CTR infrastructure would enable implementation of this architecture with a reduction in maintenance of legacy interfaces.

All of these interfaces do have a common aspect — the calibration of the interface and connecting media. The most precise interface currently used is the one pulse per second (1 pps) signal. This signal is accompanied by an appropriate time code through a separate link indicating the time epoch (unique event in time) of the pulse received. The distribution of a 1-Hz square wave pulse through distribution amplifiers, connectors, and cables introduces delays and increased noise on the signal. Delays directly contribute to an error in time, and increased noise degrades the precision with which the pulse is measured. Distributing to multiple ports increases the problem. Calibration of the distribution network solves a major portion of the problem, but calibration of the devices and media is dependent upon their environmental sensitivities, which leads to either frequent calibration or some form of active monitoring to maintain the system in calibration. Techniques for active monitoring of calibrations on board military platforms have not been fully developed.

CLOCK COMPARISON SYSTEMS

The key component technology that the CTR architecture requires is the ability to compare the clocks within and between the systems. Unless the clocks can be measured in situ, it will be very difficult to manage and distribute an accurate CTR. Combining clocks for a common composite time maintained closely to the absolute CTR requires specific continuous knowledge of the participating clocks' performances. The sidebar, "Precise Clocks," describes the current state of the art in clock technology.

Actual clock performance in the system depends on the environment in which the clock is operating. From the clock equation introduced earlier, the environmental error E is integrated over the duration of the changes in environment and is a function of many different factors. The most significant environmental factors are temperature, vibration, and variable magnetic fields. These factors can

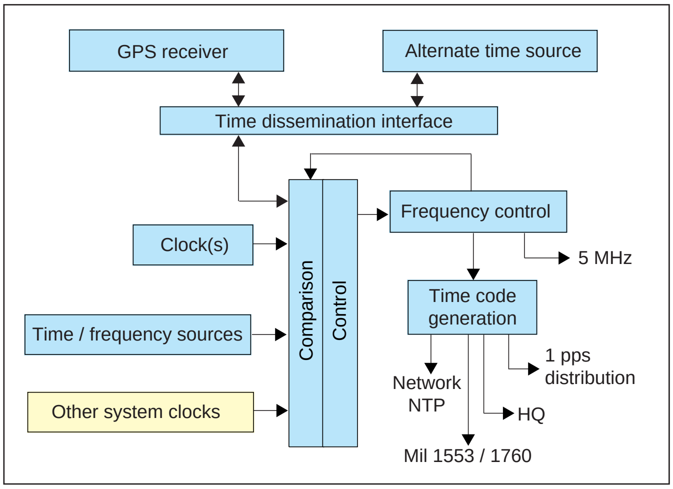

Figure 7 The common time reference (CTR) functional infrastructure would include the necessary components for generation, comparison, maintenance, and distribution of the CTR within and across systems.

have significant effects on quartz crystal oscillators and can result in a hysteresis or a response which depends not only on the current environmental conditions but also on the oscillator's recent performance history. Actual performance differences between similar clocks are also due to variable values of the frequency offset, *R*, and the frequency aging, *A*. These effects are within what would be considered normal operating limits. Complete clock failure resulting in loss of signal is not as common as abnormal jumps in frequency, phase, or aging terms. This anomalous behavior is difficult to identify without actual measurements and can seriously affect performance.

In addition to these factors that affect clock performance, the component of random noise introduced by the clock establishes its characteristic behavior. This term is typically expressed in the time domain as the square root of the Allan variance— the Allan deviation. Allan deviation is the statistical deviation of the clock signal from a mean signal phase value. This random noise component determines the ultimate stability of the clock signal and the ability to determine and predict performance. This term may change over the life of the unit, reflects environmental effects, and varies between similar units, even the same type of unit by the same manufacturer. Characterization of the clocks under operating conditions is key to management of synchronization and is, in turn, highly dependent on the ability to compare clocks.

A variety of techniques are available to provide comparison data, and some are scalable for application to mobile platforms. One of the most precise techniques is the dual mixer approach. For two clock signals nominally at the same frequency, each is mixed with a signal from a reference oscillator slightly offset in frequency. This oscillator need not be of particularly high quality. The filtered beat frequencies are out of phase proportionally to the phase difference of the two clocks. Phase com-

PRECISE CLOCKS

Precise clocks are typically the first subject in any discussion of PT&F, and are a major consideration. However, the CTR architecture is structured to take advantage of the existing precise clocks already distributed throughout military systems. The actual mix of clocks available on the subject platforms may require new technology to form a composite time group. However, new technology is now mainly focused on increased capability for very difficult problem areas in maintaining time, such as small field radios, handheld units, and weapons.

A consideration in the use of new clock technology is the general decline in the availability of high performance or unique clocks and oscillators. The telecommunications market has created a large demand for low-cost, and often low-quality, oscillators. In higher performance applications, inexpensive GPS receivers provide the accuracy. Consequently, development of precise clocks, both crystal-driven and atomic, is being conducted by service R&D agencies. Small rubidium clocks, of lesser performance than units that were previously generally available, are also being utilized in the telecommunications market. For larger platforms, these small rubidium units may be a viable supplementary capability or new capability for some uses. The highest performing units, such as cesium standards and hydrogen masers, are still relegated to major fixed stations and scientific uses.

parison can then be used as a measure of the time difference and implemented in a continuous measurement system.

The time difference values can be sampled at different rates during the normal operation of the clock without interrupting the system using the clocks. Another easily applied technique is a high-precision counter to compare the 1-pps signals generated by the subject clocks.

Whatever technique is applied, other possible uses of automated precision comparison techniques are monitoring calibration of both clocks and distribution systems, detecting degrading performance, and establishing an accurate means of switching clocks. The most significant use is to establish a basis for forming a composite time from the participating clocks.

COMPOSITE TIME

Continuous precision comparisons make it possible to form a composite time from the existing system clocks. The performance of the composite time depends upon the actual clocks involved. Composite time is a form of a clock ensemble. Clock ensembles are used to generate time scales in major timing centers, such as USNO, to establish the most accurate time scale possible. This technique involves comparing the output of a large number of identical clocks of known characteristics and applying an ensembling algorithm to form a stable, predictable time, more stable than that provided by the individual clocks. Similarities of the clocks are used to model and tune operation, and the number of clocks is a determining factor in the degree of stability improvement. For CTR composite time, the number and similarity of units to be used cannot be assured within the system clocks available. Consequently, ensembling for increased performance is not a specific objective, but ensembling would render the system insensitive to clock failure. Ensembling also increases the overall reliability of the timing system. Ensembling clocks to provide a composite time results in one clock or another dominating performance at different ranges of averaging times and provides the best performance across the spectrum of user needs.

Creating a composite from a group of clocks for CTR purposes would involve deciding which specific algorithm to apply, creating the physical connection between the clocks, establishing local clocks for comparison reference, and maintaining the resulting composite. Core clocks would provide the reference clock for the comparison of the other clocks, would maintain the mean time, and could generate a physical signal representing the mean time if necessary for the installation. Finally, a physical distribution system would have to be created to provide this signal to the user systems.

The actual composite time could be kept in the form of a "paper clock." This means that no actual physical signal is generated, only corrections to other clocks to bring them into a common time. Examples of this type of paper clock operation are the international UTC time scale and GPS Time. In both of these cases, a physical signal is not derived in the process of determining the time scale, as in the case of local UTC realizations, and for GPS the Master Control Station produces corrections that are applied with the free-running clocks in the system satellites. However, these cases also result in large numbers of time users generating physical signals synchronized to the paper clock time.

LOCAL DISTRIBUTION MEDIA

Connecting the elements of the CTR infrastructure within the systems would require distribution media. Implementation of signal distribution, along with the need to provide clock signals for comparison, could result in an overly complex and expensive distribution system for large platforms. Specific implementation of this architecture within the existing systems will need to be tailored to the specific unit.

The technique for distribution consists of cabling of various types and other types of communications media. Calibration of the media and interconnections was discussed previously. Calibration will affect much of the media, but digital data and computer networks will be especially difficult. These networks are basically asynchronous and involve unpredictable delays for processing and network switching. Techniques for time comparison and synchronization have been developed, such as the Network Time Protocol (NTP), to provide a means of synchronizing computers through Internet Protocol (IP) networks. Within the limits of the network, NTP can maintain time within computer systems synchronized to millisecond levels. Synchronous Optical NETwork (SONET) systems offer the potential to provide a synchronous means of time distribution over digital networks.

Electronic transfer devices are a distribution medium that presents unique problems. They are used for updating avionics prior to takeoff and physical transfer of data between equipment. Their ability to maintain accurate time over the intervals necessary is highly dependent on the internal oscillators. These devices present technical problems similar to those of handheld radios and GPS receivers. Interfacing them into the CTR infrastructure is another consideration that must be addressed.

The U.S. Naval Research Laboratory is currently developing a laboratory testbed to investigate the technical elements of the CTR infrastructure. The primary technical elements to be addressed first are techniques for comparison, composite time techniques, alternative time interfaces, and calibration. Demonstrations of CTR concepts with different mixes of clocks and distribution hardware will guide

FURTHER READING

For further information on network-centric warfare, see

❑ D.S. Alberts, J.J. Garstka, and F.P. Stein, *Network-Centric Warfare: Developing and Leveraging Information Superiority,* 2nd edition (revised), U.S. Department of Defense C4ISR Cooperative Research Program (CCRP), Washington, D.C., 1999. This publication is available electronically as a PDF file at the following URL: <http://www.dodccrp.org/Publications/pdf/ncw_2nd.pdf>.

❑ "Network-Centric Warfare:Its Origin and Future" by A.K. Cebrowski and J.J. Gartska, in *U.S. Naval Institute Proceedings,* 124 (1), 28–35 (1998). This article and related ones are available electronically via the CCRP Web site: <http://www.dodccrp.org/ncw.htm>.

For an introduction to timekeeping and time and frequency transfer techniques, see

❑ D.W. Allan, N. Ashby, and C. Hodge, *The Science of Timekeeping,* Hewlett-Packard Application Note AN 1289, Agilent Technologies, Inc. Palo Alto, California, 1997. This publication is available electronically as a PDF file from the Agilent Technologies Test and Measurement Web site: <http://www.tm.agilent.com/>.

❑ J. Levine, "Introduction to Time and Frequency Metrology," *Review of Scientific Instruments* 70 (6), 2567–2596 (June 1999)

For a discussion of the GPS composite clock, see

❑ K.R. Brown, Jr., "The Theory of the GPS Composite Clock" by K.R. Brown, Jr. in Proceedings of ION GPS-91, the 4th International Technical Meeting of the Satellite Division of The Institute of Navigation, Albuquerque, New Mexico, September 11–13, 1991, pp. 223–242.

For details concerning Network Time Protocol (NTP), see the NTP Web site

❑ "Time Server" <http://www.eecis.udel.edu/~ntp/>.

the determination of the effectiveness of implementing the CTR architecture.

A SYSTEM OF SYSTEMS

GPS has had a major impact on the capability to determine position and navigate military platforms and systems. The effects of providing time are just beginning to be recognized and may create an even more significant extension of military capability and operations. To take advantage of having precise time and synchronization of remote and dispersed forces with an absolute common reference, a systems infrastructure incorporating legacy systems is being developed. This infrastructure "system of systems" approach can incorporate the old with the new. The resulting military capability will achieve interoperability at the most basic level: time.

The challenges to effecting a systems approach to a CTR are more than just technical. Since they cross system and program boundaries, implementation will be programmatically difficult. To establish benefits and effectiveness, new methods for demonstration and testing under operational conditions will be necessary.

ACKNOWLEDGMENT

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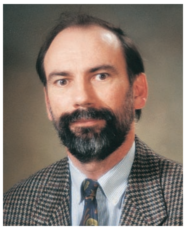
MANUFACTURER

The data shown in Figure 4 were obtained with a Precision Lightweight GPS Receiver (PLGR) from Rockwell Collins, Cedar Rapids, Iowa.

Ronald Beard has a B.S. in physics from McNeese State University in Louisiana and has done graduate work in physics at George Washington University, Washington, D.C. He was a member of the tri-service team that developed the concept and program for the Global Positioning System. Beard has worked at the U.S. Naval Research Laboratory (NRL) in Washington, D.C. since 1971 and is the head of the Space Applications Branch and program manager for the NRL GPS clock development program. He specializes in precise time and time interval technology for military navigation and communication systems.

Dr. Joseph White holds a B.S. degree in physics from Western Kentucky University in Bowling Green, and M.S. and Ph.D. degrees in physics from American University, Washington, D.C. He is the deputy head of NRL's Space Applications Branch and his principal research areas are applications of GPS time and frequency technology and use of GPS as a time and frequency source in field applications.



"Innovation" is a regular column featuring discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, who appreciates receiving your comments as well as topic suggestions for future columns. To contact him, see the "Columnists" section on page 4 of this issue.