# Scalable, High Speed, Internet Time Synchronization

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## 1. Introduction

This report covers the work done in support of the DARPA Information Technology Office program in computer networking. Contributors to this effort include Prof. David L. Mills, graduate students Qoing Li and Robert Redwinski, and undergraduate student Douglas Miller. The project continues previous research in network time synchronization technology jointly funded by DARPA, NSF, US Navy and US Army. The technology makes use of the Network Time Protocol (NTP), widely used in the Internet, together with engineered modifications designed to improve accuracy in high speed networks, including SONET and ATM, expected to be widely deployed in the next several years. Specific applications benefiting from this research include multicast topologies, multimedia, real-time conferencing, cryptographic systems, and management of distributed, real-time systems.

Recent projects reported in papers, technical reports, project reports and technical memoranda include advances in precision timekeeping technology, improved clock discipline algorithms, and engineered security models and protocols for scalable, distributed server systems. Past projects include laboratory demonstrations using advanced DSP technology for the LORAN-C timing receiver, as well as an optimum matched-filter SITOR receiver/decoder. Software developed with joint funding includes the NTP Version 3 implementation for Unix and Windows and a set of precision-time kernel modifications for major Unix workstation manufacturers. Finally, the joint projects involve the conduct of experiments designed to evaluate the success of the research and assist technology transfer to computer manufacturers and network providers.

## 2. Network Time Protocol Version 4

Our work in the design and implementation of the NTP Version 4 continued throughout the quarter; however, the departure of graduate student Ajit Thyagarajan left his work on autonomous configuration almost but not quite complete. On the other hand, we have made considerable progress in the implementation of the security model and authentication scheme. Most of the work required is in the area of security key management and provisions for reliable key generation and lifetime enforcement.

## 3. WWV/H Timing Receiver

It has always been a matter of concern to deploy many more NTP primary (stratum-1) time servers at convenient locations in the Internet. However, provisioning of radio or satellite receivers has been a problem, both because of their relatively high cost and also because of their antenna requirements. Antennas for current GPS, WWVB, GOES and LORAN receivers must be located outside the building, usually on the roof, and require connecting cables to the receiver itself, which is usually located in a machine room or office.

In an effort to find solutions to these problems, a relatively inexpensive LORAN-C receiver was constructed some time ago. The receiver was built as a plug-in card for an Intel-based processor running sophisticated algorithms designed to reliably synchronize to signals degraded by moderate to severe local radio interference and noise. This receiver has been in continuous service functioning as a backup to our GPS and cesium-based gear.

However, replication of this receiver is not likely, since the LORAN-C system has only a few years of life remaining before closedown. Accordingly, a search was made of inexpensive alternatives based on other time dissemination services. A constraint in the search was that the cost be moderate, require a minimum of external hardware and be implemented primarily in software. An obvious choice is the telephone modem services operated by NIST and USNO, but these require periodic connection and in general a dedicated telephone line.

Of all the radio and satellite time dissemination services operated by the US and Canadian governments, the shortwave transmissions from stations WWV, WWVH and CHU require the least investment in receivers and antennas. In most areas, an inexpensive shortwave receiver and hank of wire tossed out the window is sufficient to deliver a signal that can be interpreted by ear. However, traditional ways to demodulate and decode the audio signal still require special purpose hardware and a microprocessor.

Observing that modern workstations are getting faster each year, a project was initiated to explore implementing the demodulation and decoding algorithms in the workstation itself, with input from the audio codec that is now ubiquitous. One of the requirements was that the algorithms must be very good - near theoretically optimal, in fact - since the antenna is crude and the receiver frequency cannot be controlled.

Initially, it was not clear that the extensive processing required could be done in an ordinary workstation, so a prototype implementation was built using a Texas Instruments TMC-320C25 DSP processor. The software program implements a maximum a-priori probability (MAP) demodulator/decoder optimized for the WWV timecode modulation format. In tests, it has outperformed commercial WWV receivers by an order of magnitude in accuracy and delivered reliable timecode data when the signals were too weak to be heard by ear and long after the commercial receiver gave up. A technical report [1] on the design, implementation and testing is available, along with a software distribution available for network download.

## 4. SNMP project

As described previously, a project has been started to develop a MIB for NTP. This is an issue which has been dormant for some years. Comprehensive provisions for remote monitoring and control of NTP servers and clients were included in the original NTP Version 2 software, which appeared well before SNMP became available in any form. Prof. Adarsh Sethi of the Computer and Information Sciences Department volunteered his time and that of his graduate student to specify a MIB and implement prototype software to provide SNMP support usable by available management programs. A preliminary MIB specification is being developed and extensions to available SNMP agent software is under construction.

## 5. Plans for the Next Quarter

Our plans for the next quarter include continued testing and refinement of the NTP Version 4 protocol model, specification and implementation. In addition, we will continue development of the SNMP implementation and MIB for NTP. Finally, we plan to port the DSP software developed for the WWV timing receiver to the C language for possible deployment at other sites.

## 6. Publications

1. Mills, D.L. A precision radio clock for WWV transmissions, Electrical Engineering Report 97-8-1, University of Delaware, August 1997, 25 pp.

   Abstract

   This report describes a software program that functions as a radio clock using shortwave radio signals transmitted by National Institute of Standards and Technology (NIST) radio stations WWV and WWVH. Operated in conjunction with an inexpensive, fixed-frequency shortwave radio, it has nominal timing errors less than 125 μs when tracking one of the stations and frequency variations less than 0.5 parts-per-million (PPM) when not tracking either station. The clock produces an ASCII timecode that can be used to set the time of another device, such as a computer, as well as precision reference signals that can be used for other purposes, such as to drive laboratory test equipment.

   The primary motivation for this report is as an example and case study of optimum demodulator and decoder design using a maximum likelihood approach and matched filter, synchronous detection and soft decision principles. The clock discipline is modelled as a Markov process, with probabilistic state transitions corresponding to a conventional time-of-century clock and the probabilities of received decimal digits. The result is a performance level which results in very high accuracy and reliability, even under conditions when the one-minute beep from the WWV/H signal, normally its most prominent feature, cannot be detected by ear with a sensitive communications receiver.