Living Document

Proposal for a Statewide California Real Time Network
Version 5.0

California Spatial Reference Center
Scripps Institution of Oceanography, La Jolla, CA

October 16, 2008

Prepared by

Yehuda Bock, CSRC Director
Maria Turingan, CSRC Coordinator
CRTN Review Committee:
Art Andrew (Chair)
Gigi Cardoza
Ross Carlson
Chris Walls
Cecilia Whitaker

Please send comments to
ybock@ucsd.edu & Art.Andrew@rdmd.ocgov.com

Table of Contents

Introduction

We propose to develop a statewide real-time data and positioning service, the California Real Time Network (CRTN), which is tied directly to the California Spatial Reference System (CSRS) and the National Spatial Reference System (NSRS). The proposed free public service fulfills the requirements of the California Public Resources Codes for GPS-derived coordinates and orthometric heights.

CRTN is a multipurpose network which utilizes well over $100 million dollars of existing geophysical infrastructure in California. It also serves as a test bed for developing early warning systems for geological (earthquakes, tsunamis, volcanos, landslides) and atmospheric (flood control) hazards.

This proposal deals with the data and positioning service addressing two related issues:

(1) The lack of an open, uniform and seamless statewide real-time network in California. Our State with its size, population, unique spatial referencing environment, and despite the tremendous resources at its disposal is far behind in providing a real-time infrastructure for precise spatial referencing, a requirement for increased economic productivity and innovation in private and public sectors for a growing number of interrelated applications.

(2) The crisis in federal funding of the California Spatial Reference Center (CSRC) and the absence of State support and funding. The CSRC has essentially met its goals with respect to passive stations as outlined in its Master Plan for a Spatial Reference Network published in 2002 (with the endorsement of NGS in 2003), and is ready to tackle the long-term goals described in the Master Plan, specifically "real-time infrastructure systems[1]."

In addition to providing a much needed public utility to our traditional users in the surveying community, a successful effort could benefit such areas as

- GIS/geodetic framework
- Monitoring of critical life lines
- Disaster preparedness and response
- Relief efforts
- Flood plain management
- Water transportation infrastructure
- Precision agriculture
- International and offshore boundary mapping
- Aircraft landing and safety systems
- Intelligent transportation and telematics
- Fleet management
- Coastal and harbor navigation

Figure 1 shows the proposed statewide network with a maximum spacing of 80 km based on existing stations from geophysical networks. Also shown are stations that are already providing real-time data streams.

[1] See http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf (p. 6)

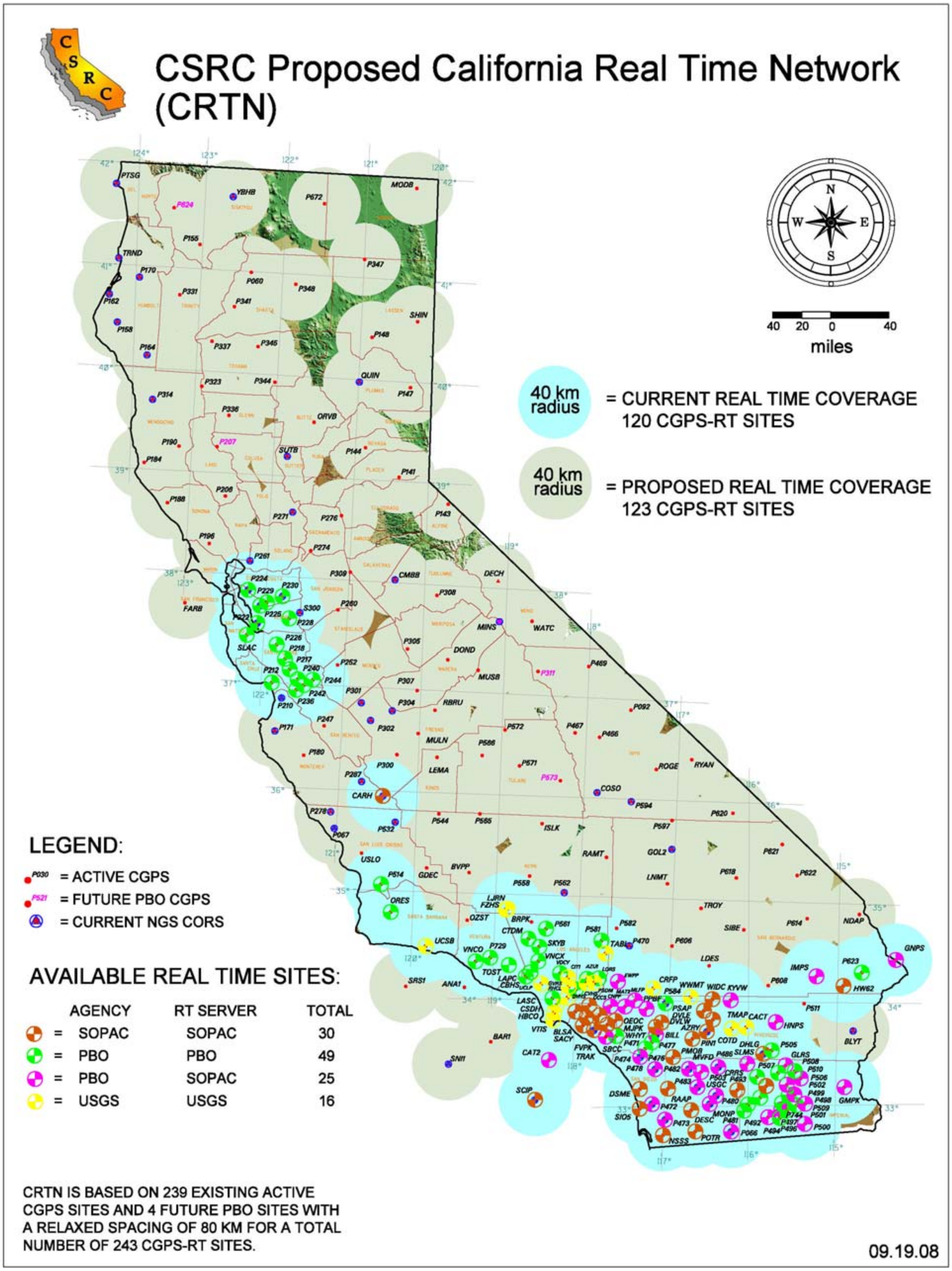

Figure 1. Map of proposed statewide CRTN with a maximum spacing of 80 km

Elements of a Proposed Statewide CRTN Infrastructure

The salient points of the proposed real-time data and positioning service are summarized below and discussed in more detail in later sections of the proposal.

- Builds upon the more than $100 million dollars of existing geophysical infrastructure already invested in California
- Builds upon existing (approximately 80) CRTN stations in southern California, operated since 2003 by SOPAC[2], USGS[3], PBO[4], Orange County[5], San Diego County[6], and MWD[7] (Figure 1)
- Requires a partnership with existing geophysical networks (USGS, SOPAC, PBO, BARD[8]) to expand real-time infrastructure throughout the State
- Uses only continuous GPS (CGPS) stations that are part of the California Spatial Reference Network (CSRN), and built for high-accuracy, longevity, and geophysical stability
- Leverages existing metadata/archive infrastructure, web services, and software at SOPAC/CSRC including the SECTOR[9] velocity model and HTDP[10] crustal motion model, to provide seamless real-time epoch-date positioning (kinematic and dynamic) using standard GNSS[11] formats
- Is directly tied to the California Spatial Reference System (CSRS) and National Spatial Reference System (NSRS), which fulfills the requirements of the California Public Resources Codes 8856(c)(e), 8857(c), and 8858(b) for GPS-derived geodetic coordinates and orthometric heights.
- Provides on-the-fly orthometric heights through national geoid models supplemented with local corrections
- Is able to recover from large seismic events by near-real-time monitoring of changing site positions, followed by rapid geophysical modeling and updates to SECTOR and HTDP models
- Contributes to and uses national real-time atmospheric propagation models (troposphere and ionosphere)
- Takes advantage of other satellite constellations such as GLONASS[12] and the European Galileo system, and new signals available from the GPS satellites[13]

---

[2] SOPAC – Scripps Orbit and Permanent Array Center
[3] USGS – United States Geological Survey (Pasadena Office)
[4] PBO – Plate Boundary Observatory, University NAVSTAR Consortium (UNAVCO) EarthScope project
[5] Orange County Public Works
[6] San Diego County Department of Public Works
[7] MWD – Metropolitan Water District of Southern California
[8] BARD – Bay Area Regional Deformation Array (operated by UC Berkeley in northern California
[9] SECTOR – Scripps Epoch Coordinate Tool and Online Resource tool that calculates epoch (date) specific coordinates
[10] HTDP – Horizontal Time Dependent Positioning: NGS software that enables users to predict horizontal displacements and/or horizontal velocities related to crustal motion in the United States and its territories, implemented in a web services environment by SOPAC/CSRC
[11] GNSS – Global Navigation Satellite System (e.g., GPS, GLONASS, Galileo)
[12] GLONASS – Russian global navigation constellation
[13] This will require either receiver or firmware upgrades to existing stations

- Has a 20-80 km spacing, with data streaming 24/7 and latency of 1 second
- Provides open access to single-base RTK (real time kinematic) positioning and to multiple station raw data streams in their streaming format
- Requires no user fees and provides unrestricted access to data and positioning service
- Provides redundant backup services at other locations
- Is operated by the CSRC operations center at SOPAC with management and governance provided by the CSRC Executive Committee and CRTN consortium operating through the existing UCSD Support Group
- Is funded by contracts between public agencies and the SOPAC recharge facility, overseen by the CSRC Executive Committee and CRTN consortium

Current Situation

CRTN is operational (approximately 80 stations) and provides complete real-time coverage with a latency of less than 1 second for the five southernmost California counties (Imperial, Los Angeles, Orange, Riverside and San Diego) (http://sopac.ucsd.edu/projects/realtime/) (Figure 1). Single-base RTK is fully supported through a variety of open protocols (RTCM[14], NTRIP[15]). Real-time raw data streams are limited to one station per user. PBO has also started to provide real-time data streams in RTCM and BINEX[16] formats. Figure 1 shows the current availability of real-time data streams.

Description of CRTN and Its Components

In this section we describe the real-time data and positioning service that will be available

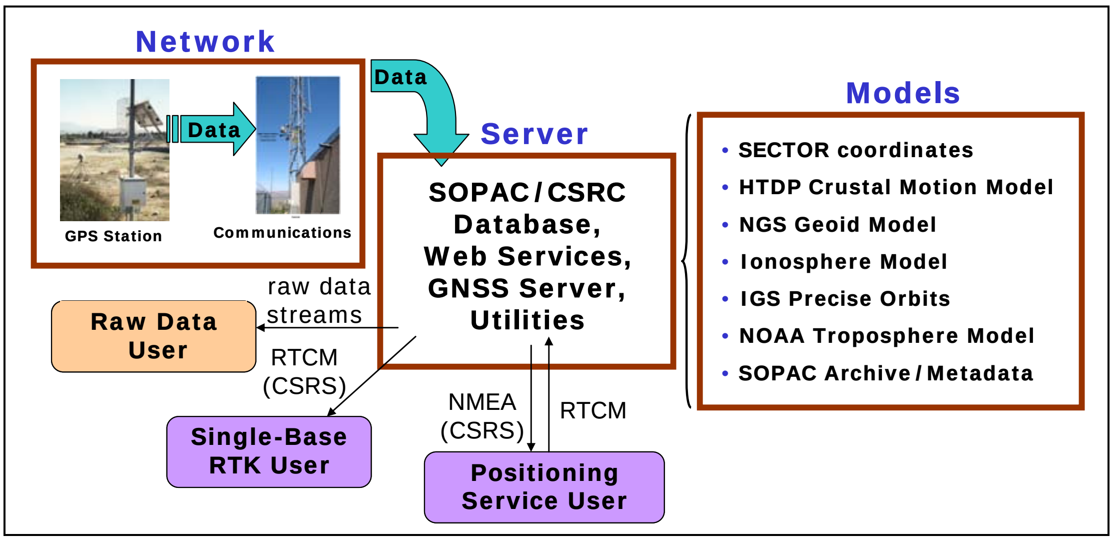

Figure 2. Components of CRTN Data and Positioning Service

[14] RTCM – Radio Technical Commission for Maritime Services (protocols for streaming real-time GNSS data)
[15] NTRIP – Networked Transport of RTCM via Internet Protocol
[16] BINEX – Binary (Receiver) Independent Exchange Format, developed by UNAVCO

through the statewide CRTN., The components of CRTN are shown in Figure 2. We describe the salient points of each component.

The CRTN User

CRTN supports three basic user functions:

(1) Raw data streaming – the user can request multiple raw receiver streams (IP ports) in the native streaming formats received by CRTN (e.g., Ashtech MBEN, Leica LB2, Trimble RT17, UNAVCO BINEX, RTCM).
(2) Single-base RTK – the user can request RTCM (2.2, 2.3, 3.0) data from a station (single IP port or NTRIP) to perform single-base RTK positioning.
(3) Epoch-date positioning – For those familiar with positioning services such as OPUS and SCOUT, CRTN provides the same basic positioning function but in real time and for kinematic, dynamic or rapid static applications. Simply put, the user streams GPS/GNSS data, associated metadata, and a desired epoch date to an IP port, and receives back a stream of epoch-date geodetic coordinates (latitude, longitude, and ellipsoidal height) and orthometric heights, tied to the CSRS/NSRS.

Data and positions flow once a second, with a latency of about 1 second.

The Network

The reference network consists solely of stations that were built for highest-order geodetic accuracy, longevity, and geological stability. The basic station design consists of a geodetic-quality dual-frequency GPS/GNSS receivers, a GPS antenna (Dorne-Margolin antennas with chokerings are standard throughout the network), and a shallow- or deeply-anchored anchored GPS monuments (Figure 3). The network was built in southern California by SCIGN[17] (and its predecessor the Permanent GPS Geodetic Array – PGGA), and later adopted by the PBO for the Western U.S. Thus, CRTN leverages well over $100M invested by the geophysics community since 1991 in GPS monitoring infrastructure in California, specifically existing SCIGN and PBO stations, and other stations built according to the same design. Access to real-time data streams from these stations requires the cooperation and support of the existing geophysical

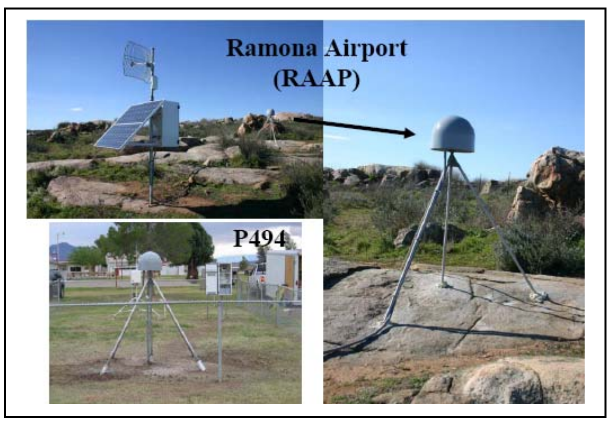

Figure 3. Photos of two CRTN stations. Station RAAP was built by San Diego County Dept. of Public Works to SCIGN standards, including a shallow-anchored braced monument. PBO station P494 has a deeply-anchored braced monument.

[17] SCIGN – Southern California Integrated GPS Network

networks (i.e., USGS, SOPAC, PBO, BARD), and pertinent discussions are underway with these data providers.

This proposal builds upon (approximately 80) existing CRTN stations in southern California (Figure 1), installed and operated beginning in 2003 by SOPAC, USGS (Pasadena office), PBO, Orange County, San Diego County, and Metropolitan Water District. The network includes several types of real-time communications links (spread spectrum radios, microwave, cellular modems). The GPS data are streamed at a 1 Hz rate (once per second) in a variety of formats with latency of 1 second or less. These formats include:

(1) Raw receiver formats, e.g., Ashtech MBEN, Trimble RT17, Leica LB2
(2) BINEX format (receiver-independent binary data developed by UNAVCO) and the primary streaming format for PBO stations[18]
(3) RTCM (versions 2.2, 2.3, 3.0) through IP Ports or NTRIP

All existing and proposed CRTN stations are part of the California Spatial Reference Network (CSRN), which is integrally tied to the existing metadata/archive infrastructure at SOPAC/CSRC. Therefore, the stations are directly tied to the California Spatial Reference System (CSRS) and National Spatial Reference System (NSRS) through the SECTOR velocity model provided by SOPAC and the HTDP crustal motion model provided by NGS (and available through web services by SOPAC/CSRC). CRTN is able to recover from large seismic events by near-real-time monitoring of changing site positions, followed by rapid geophysical modeling and updates to the SECTOR and HTDP models. This allows seamless, timely, and accurate epoch-date conversions. Furthermore, using these stations fulfills the requirements of the California Public Resources Codes (8856(c)(e), 8857(c), 8858(b)) for GPS-derived coordinates and orthometric heights, as provided by statutes that became effective on January 1, 2007.

The complexities of the reference network are transparent to the CRTN user. It is CRTN's responsibility to ensure that the data flow reliably and with low latency from the stations or other data servers (e.g., at UNAVCO in Boulder, Colorado) to the CRTN server.

The CRTN Server

The "CRTN Server" (Figure 2) consists of several integrated components: the SOPAC Oracle database and web services, the SOPAC/CSRC archive, and a real-time GNSS Server (currently Geodetics, Inc. RTD Pro and CommLinkProxy). The real-GNSS Server is the first point of contact with the CRTN data streams and performs multiple functions. These include:

(1) GPS receiver control for stations that are maintained by SOPAC
(2) Recording of raw data streams and transfer to the SOPAC archive
(3) On-the fly creation and recording of RINEX files and transfer to the SOPAC archive

[18] BINEX format is an attractive streaming format since it is receiver independent, is not expected to change, and contains the full data content produced by the GPS receiver (unlike RTCM formats)

(4) Computation, recording, and transfer to archive of 1 Hz instantaneous true-of-date positions and displacements, using ultra-rapid orbits computed by SOPAC and the NOAATrop real-time tropospheric delay model computed by the National Oceanic and Atmospheric Administration (NOAA).
(5) Transfer of 30-minute RINEX files to NOAA for incorporation into its NOAATrop model for the continental U.S.
(6) Single station data stream in various RTCM formats to CRTN users for single-base RTK
(7) Multiple station raw data streams in their streaming format to CRTN users
(8) Recording and storing all real-time transactions with users.

The CRTN Server provides the epoch-date positioning service. The complexities of the different components of the CRTN server are also largely transparent to the user. It is CRTN's responsibility to ensure that the various data services are reliably available to users with low latency.

The Models

One of the primary advantages of the CRTN positioning service, is the ability to apply various models at the server, without having to bundle this information to the user. These include:
(1) Models to improve the accuracy of GPS network processing, for example the NOAATrop real-time troposphere delay model available for the continental U.S., ultra-rapid precise orbits computed operationally by SOPAC for the IGS community, and ionosphere models (these may become more important as we move into the peak of ionospheric activity starting in 2012).
(2) Positioning models such as SECTOR coordinates and velocities to assign true-of-date coordinate constraints for the reference stations, and HTDP crustal motion model (currently 3.0) for converting true-of-date geodetic field coordinates to user-specified epoch dates (such as 2007.0);
(3) Geoid models (such as GEOID03) with the possible addition of local geoid corrections).

The CRTN positioning service is directly tied to the latest realizations of ITRF (currently ITRF2005) and NAD83 (currently NSRS2007), the California Spatial Reference System (CSRS) and National Spatial Reference System (NSRS) through the SECTOR velocity model and the HTDP crustal motion model, and provides seamless epoch-date coordinate conversions. It also fulfills the requirements of the California Public Resources Codes for GPS-derived coordinates and orthometric heights.

CRTN's positioning service (Figure 2) leverages existing metadata/archive infrastructure at SOPAC/CSRC, and is fully integrated with SOPAC web services and software applications. The complexities of "The Model" are also transparent to the CRTN user. It is the responsibility of CRTN to keep the models current.

Data Availability and GNSS Software

All data and position services will be openly and freely available. There have been comments to the effect that the data and positioning service provided by CRTN will compete with the private sector. On the contrary, CRTN will provide free and open access to state-of-the-art real-time infrastructure at nominal 80 km spacing in California leveraging over $100M in Federal investments in geophysical networks. Furthermore, CRTN will provide direct access to the CSRS and NSRS, which is consistent with the CSRC's mandate and Master Plan, and fulfills the requirements of the California Public Resources Codes for GPS-derived coordinates and orthometric heights.

As detailed above the CRTN server is a combination of several integrated components: SOPAC web services and database, SOPAC on-line utilities, and the Geodetics, Inc. RTD Pro software. SOPAC licenses the software from Geodetics. It is used to support NASA- and NOAA-funded research into early warning systems for geological and atmospheric hazards as well as to provide CRTN data services. SOPAC is able to sole source to Geodetics because of the unique and multi-purpose capabilities of the RTD Pro software, which are not currently available from scientific or other commercial GPS network software packages, and the willingness of Geodetics to make software changes to support SOPAC. SOPAC is open to testing other solutions as they become available. In any case, it is transparent to CRTN users and/or partners as to what software runs the positioning service. To neutralize any conflict of interest issues, CRTN funds will not be used to purchase software licenses from any GNSS vendor.

GNSS vendors may modify their field data software to take advantage of CRTN's positioning service. Since all GNSS vendors make ample use of other SOPAC services in some of their proprietary software, it is reasonable to assume that they would make simple modifications to accommodate customer requests for access to the CRTN positioning service. It is also reasonable to assume that they would be willing to become CRTN underwriters, rather than each one having to create their own reference station infrastructure. In any case, raw data streams will be freely available without restrictions so that value-added services can be generated by any user.

Management and Governance

For the purpose of management and governance interested parties will fall into three categories;

(1) CRTN Users
   a. Single Station Users (single-base RTK)
   b. Multiple Station Users (raw data streams)
   c. Positioning Service Users (epoch-date positions tied to CSRS/NSRS)

(2) CRTN Underwriters (funding sources)
   a. Public Agency Underwriters – from public sector such as SGIO[19], DWR[20], Caltrans
   b. Other underwriters who may wish to contribute to CRTN

[19] SGIO – Proposed State Geospatial Information Office
[20] DWR – California Department of Water Resources

(3) CRTN Providers – partners that support CRTN by providing station data and/or infrastructure; existing CRTN providers include PBO, Orange County, San Diego County, MWD, USGS (Pasadena Office), and SOPAC

The CRTN statewide expansion provides an important spatial referencing utility for California. Therefore, it is important to define an appropriate management and governance structure, with clear lines of authority, responsibility, and delegation. Our proposal is to take advantage of the existing CSRC governing structure and the SOPAC/CRTN and geophysical infrastructure developed over the last decade. It is anticipated that once the system is fully developed and operational, the management and governance of CRTN will evolve to reflect changing circumstances.

In the meantime, our proposal is that the governance of CRTN (see Figure 4) will be provided by the CSRC, through its role as a UCSD Support Group. The Support Group umbrella currently includes CSRC Bylaws, the CSRC Coordinating Council (CC), and the CSRC Executive Committee (EC). The CRTN Consortium will be formed with its own set of bylaws but accountable to the CSRC EC. The CRTN consortium will assume the authority and responsibility to manage and govern, and delegate the development of the project to the SOPAC Director. In addition to serving as a Center at SIO, SOPAC serves as a mechanism for service contracts to be entered into by the University. CRTN will operate through service contracts to the SOPAC recharge facility. The CSRC EC or members of the consortium will provide management of CRTN through these contracts. In the consortium model, each entity that enters into a contract with the University will be considered a CRTN Underwriter.

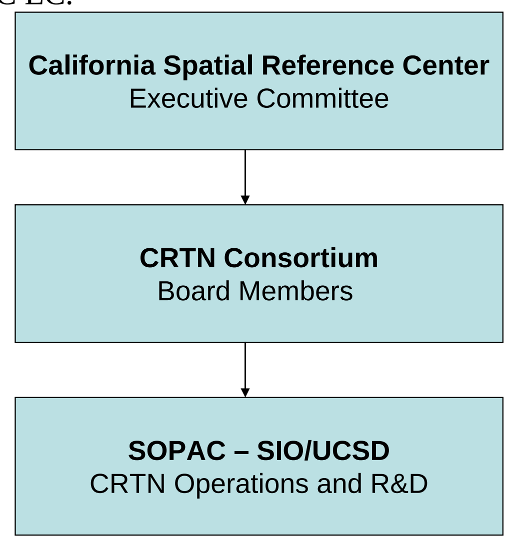

Figure 4. Governance of CRTN

Cost Recovery

It is important that the costs of CRTN be evaluated properly, something that is complicated by the multiple ownership of some of the components. For example, the costs of maintenance of the PBO stations, in particular the real-time component, should be shared by CRTN and the budget should reflect this. Another example is the communications for the existing southern California network, which is currently being supported to a large extent by the NSF-funded HPWREN[21] network at UCSD. Currently this capability is available for free; but HPWREN's continued existence will depend on the renewal of NSF support, something that is never assured.

[21] HPWREN – High-Performance Wireless Research and Education Network

Our goal is that CRTN be funded as a free and open public service, for example through a single state agency such as the Department of Water Resources, Caltrans or the new State Spatial Information Office (SGIO). It will take time to get public funding, and this is something that will be pursued vigorously by the CSRC. In the interim, we will also reach out to partners at local public agencies such as counties and semi-public entities such as water districts. There is a precedent for this. For example, the Riverside County Flood Control and Water Conservation District, the Riverside County Department of Transportation, and Caltrans have contracted in the past with SOPAC for services. We will also set up a mechanism for other underwriters who may wish to contribute to CRTN.

SOPAC will develop an annual budget for CRTN, including a justification of costs. The budget and rates will be negotiated by SOPAC and the Consortium on an annual basis.

Each contract must conform to University requirements. It should be noted that warranties cannot be stipulated in University contracts.

Consortium funds administered through SOPAC could be used to subcontract services to others, such as UNAVCO, for use of real-time data from PBO stations.

Additional Information

The following are available:

(1) CSRC Master Plan for a Modern California Geodetic Control Network (http://csrc.ucsd.edu/input/csrc/csrcMasterPlan.pdf).
(2) Presentation by Y. Bock for 2008 CLSA/CSRC RTN seminars ("California Real Time Network: Rationale, Results and Future Plans" – accessible at anonymous ftp://dozer.ucsd.edu/pub/public/CRTN_WhitePaper - filename Bock.ppt.
(3) Presentation by Y. Bock for Sept. 5, 2008 NGS/CSRC/Caltrans meeting at Scripps ("Status of California Real Time Network Proposal" – accessible at anonymous ftp://dozer.ucsd.edu/pub/public/CRTN_WhitePaper - filename CRTN_Status.pdf).
(4) Comments on previous versions of this proposal – accessible at http://csrc.ucsd.edu/input/csrc/proposals/CRTNProposal_version4.0.pdf