Technical Note TN-2674

Providing Synchronization to Tait Networks

November 2017

For operational and regulatory reasons, many radio networks need accurate timing at each base station site. Loss of timing can be catastrophic. This document will help in avoiding single points of failure that affect critical sites or the entire network. It explains what 'good timing' is essential for Tait simulcast and voted channels (whether TB9100, TB9400, TB9300 or TB7300). It replaces TN-2411 and covers:

- Timing robustness improvements to the TB9400 (NTP free-run and reference to multiple NTP servers).
- The addition of DMR voting and simulcast (TB9300 and TB7300).

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Timing and Synchronization for Tait Base Station Networks

Tait base stations need accurate timing and synchronization for several reasons:

- Radio operator license conditions require base stations to operate on a tightly controlled frequency. In some higher frequency bands, the native base station oscillator is not sufficiently accurate, so an external frequency reference is needed.
- Simulcast channels (whether P25, analog or DMR) require accurate transmit timing for simulcast to work properly.
- TDMA channels with voting (whether P25 Phase 2 or DMR) require accurate slot timing so that slots align properly at different sites.
- P25 Phase 2 requires frame structures to be aligned across the channels at a site to minimise re-acquisition time when a radio terminal moves to a channel. (Refer TIA.102-BBAC 3.4.1—TDMA Channel Alignment.)

Channel Group Operation

This section introduces terminology and explains what a channel group needs for proper functioning.

In this document 'synchronization' means that a base station has its essential timing inputs and that these satisfy some sanity constraints. Tait networks are designed to be synchronized to GPS disciplined timing references. Timing units based on GPS give highly accurate, synchronized timing outputs.

Different channel types have different synchronization needs:

- Frequency references are required for simulcast operation and in higher frequency bands.
- NTP is recommended for all multicast or simulcast operation because accurate log timestamps allow event correlation across logs.
- TDMA channels (Time Division Multiple Access, as used in P25 Phase 2 and DMR) require accurate slot synchronization for voting to work properly. Tait base stations require a 1PPS pulse and an NTP time source, both GPS disciplined.
- Simulcast channels require highly accurate transmit timing for simulcast to work as expected. To fulfil this requirement Tait base stations use the 1PPS pulse and NTP time source, both GPS disciplined.

Some additional constraints are:

- Base stations in a channel group comprise a single master with a number of satellites. A simulcast channel requires the master to have synchronization since it is responsible for defining the transmit launch time instant.
- Base stations provide a (simulcast) 'Transmit when unsynchronized' configuration flag in the channel group profile. It allows you to prioritise areas of FM capture (transmit no matter what) versus areas of overlapping coverage (don't transmit unless synchronized). The configuration flag doesn't apply to P25 Phase 2 because Phase 2 transmissions must be site-aligned. Phase 2 base stations never transmit with simulcast or TDMA unsynchronized, regardless of the flag setting.
- TDMA non-simulcast voted channels (used in DMR) still depend on transmitter and receiver synchronization, because successful base station receiver voting requires slots to begin and end at the same time across the voted sites. The accuracy requirement is sub-millisecond rather than microsecond, but base stations use the same timing mechanisms for receiver voting (non-simulcast) and simulcast.

To transmit or not transmit when unsynchronized

Base stations that lose their inputs from the GPS timing unit immediately become unsynchronized. They can be configured to either transmit or not transmit while in this state.

If the base stations at a physical site are configured to transmit when unsynchronized, they revert to Phase 1 and cause all other sites in the channel group to also revert to Phase 1. This causes a dramatic reduction in capacity, but preserves full coverage.

If the base stations at a physical site are configured to cease transmitting when unsynchronized, the rest of the network continues operating in Phase 2. This preserves capacity but loses the coverage that the site provided.

Hence there is a trade-off between coverage and capacity. If the site involved is the main site, it may be best to have the base stations continue transmitting to preserve coverage. If the site is one of a number of overlapping sites, it may be best for the base stations to cease transmitting to preserve capacity and lose little in the way of coverage.

Base Station Timing Requirements

- Temperature range (recommended): -30 — +60° C.
- The timing unit must provide all of: frequency reference output; 1PPS output; NTP output; all from a common (GPS) time-base.
- Holdover on loss of GPS input: recommended for mission critical operation.
- SNMP monitoring and alarms: recommended.

Frequency reference input

- Connector: BNC.
- Frequencies: 10 / 12.8 MHz.
- Level: -30 — +20 dBm
- Frequency accuracy: small number of ppb for simulcast operation.
- Drift: < 1us / four hours recommended.

1 PPS input

- Connector: BNC.
- Signal level: 3v3 nominal
- Impedance: Drive 50 Ohm load.
- GPS disciplined: required.
- Accuracy (pulse edge): +/- 50 ns

NTP input

- NTP protocol version: 4
- GPS disciplined: required.
- Properly signal leap seconds: required.

Technical Topics — Base station synchronization

This section applies only to Tait TB7300, TB9300 and TB9400 base stations.

Simulcast synchronization means base stations are able to transmit the same signal with microsecond accurate timing.

TDMA synchronization involves two capabilities:

- The ability for transceivers at distinct sites to transmit and receive with the same slot timing, to ensure that mobile radio slot timing is consistent.
- The ability to time-align channels at a site so as to improve radio channel acquisition time.

TDMA synchronization requires accuracy in the order of a few hundred microseconds. Tait base stations use the same timing subsystem for both simulcast synchronization and TDMA synchronization.

The TB7300 and TB9300 base stations designate TDMA synchronization as 'receiver synchronization'. This means successful receiver operation in a multicast channel requires TDMA slot synchronization.

The TB9400 base station designates TDMA synchronization as site alignment.

Tait base stations have two distinct time-bases:

- Wallclock time or time-of-day is established and maintained by the NTP subsystem, in the same way as many other network devices. Wallclock time may or may not be micro-second accurate.
- Air interface timing defines simulcast and TDMA synchronization. It must be microsecond accurate, and the timing reference is defined by the 1PPS hardware input. TB9100 series base stations do not require wallclock time for simulcast synchronization: 1PPS input is sufficient for simulcast operation.

The air interface timing of Tait base stations does require wallclock time for TDMA frame synchronization, site alignment (P25 Phase 2) and improved resilience to network delays. NTP failures can therefore be a failure mode for base station simulcast and TDMA synchronization. These base stations can free-run the wallclock once it has been synchronized by NTP. Loss of NTP will raise an NTP alarm, but will not cause simulcast or TDMA synchronization failure.

Timing inputs for different modes of operation with different base stations

Frequency Reference, all base stations (TB9100, TB7300, TB9300, TB9400)

Synch	Frequency <700 MHz	Frequency > 700 MHz
Single base station	Not required	Required
Multicast FDMA	Not required	Required
Multicast TDMA	Not required	Required *
Simulcast	Required	Required

Notes

* If base station supports operating mode.

1PPS, all base stations (TB9100, TB7300, TB9300, TB9400)

Synch	1PPS
Single base station	Not required
Multicast FDMA	Not required
Multicast TDMA	Required *
Simulcast	Required

Notes

- * If base station supports operating mode.
- 1PPS pulse must be GPS disciplined.

NTP

Synch	TB9100	TB7300 / TB9300 / TB9400
Single base station	Recommended *	Recommended *
Multicast FDMA	Recommended *	Recommended *
Multicast TDMA	N/A	Required
Simulcast	Not required	Required

Notes

- * Timestamps with correct time-of-day (millisecond accuracy) greatly assist fault diagnosis using log event information, especially when correlating events from multiple base stations and other network devices.
- TB7300, TB9300, TB9400 base stations use NTP to disambiguate seconds information in addition to 1PPS (required for TDMA and simulcast).

Technical Topics — NTP

This section applies only to Tait TB7300, TB9300 and TB9400 base stations.

It explains how these base stations use Network Time Protocol and offers some recommendations for good practice. (TB9100 simulcast synchronization doesn't depend on NTP.)

Information provided here is from the NTP document archive (ntp.org) which has version specific documentation. At time of writing, version 4.2.8p1 is applicable to these base stations.

NTP can be viewed as an entire subsystem.

- It is a protocol that communicates time information and allows clock synchronization.
- It is a distributed algorithm that can provide a single consensus time estimate.
- It has a set of functions that adjust and groom the device clock so as to ensure continuity and sanity of time values.

NTP has a number of rules intended to produce the best quality estimate of the time:

- NTP can operate in a peer to peer model or a client / server model, where clients can themselves become servers to other clients. The NTP stratum indicates how many levels exist between a client and the source of time. A GPS based timing reference is called a primary server and has a stratum level of 1. A base station referring to a timing reference would therefore have a stratum level of 2.
- Tait base stations are not intended to be NTP peers or servers. You should configure base stations to point to primary servers (recommended) or secondary servers whose purpose is to distribute time information.
- NTP provides timing resilience by allowing clients to refer to many servers. NTP clock selection algorithms discard servers that do not meet NTP's sanity conditions. They are called *falsetickers*. The remaining servers are called *truechimers*.
- Tait base stations use the standard operating system NTP daemon function. An NTP alarm means the NTP daemon is unable to provide a consensus time value, and is not adjusting the CPU clock (wallclock time). Tait base stations have specific rules that determine whether the base station has TDMA synchronization or simulcast synchronization based on the status of NTP. The rules are summarised under 'Free run' next page.
- Tait base stations allow you to enter up to three server addresses, with one designated as the preferred server. The NTP subsystem also uses the 1PPS input, if it is present, associating it with the preferred server. Assuming the preferred server is GPS disciplined, the combination of 1PPS input

and NTP protocol means that the time reference source provides wallclock time with microsecond accuracy. The recommended configuration is to use a local GPS based timing reference for 1PPS and preferred NTP server address input.

It is useful to view NTP as the thing that adjusts the time, rather than the thing that keeps the time. This document uses the term 'wallclock time' for the base station timekeeping function.

- On start-up, until NTP is able to provide a time estimate, base station wallclock time is some time after 1 January 1970.
- If NTP is operating nominally, wallclock time will be accurate to a few milliseconds on a good network.
- On a Tait base station, if NTP and 1PPS inputs are both nominal, wallclock time will be accurate to fractions of a microsecond.
- On a Tait base station if NTP is synchronized, and NTP subsequently fails, wallclock time will free-run, and simulcast and TDMA synchronization depend on the integrity of the 1PPS input.

Free run

Tait base stations require NTP, disciplined to the GPS network, to convey time-of-day and disambiguate the accurate 1PPS pulse. These base stations don't gain simulcast or TDMA synchronization until NTP provides a time-of-day (wallclock time) output. If a base station loses NTP time (signified by an NTP alarm) the base station can free run its wallclock time and maintain time synchronization. Thus, there may be an NTP alarm without simulcast or TDMA alarms.

A base station with free-running wallclock time will maintain synchronization indefinitely, given a valid 1PPS input, but some user operations can restart NTP, causing free run to end, with loss of synchronization if the base station is unable to regain wallclock time after NTP restarts.

User actions with their effects are listed below:

Action	Free run	Simulcast / TDMA synchronization
Start up	No	NTP and PPS are required
Base station online / offline	Not affected	Unchanged
Change Phase 1 / Phase 2 (P25)	Not affected	Unchanged
Change NTP server address(es)	Ends	NTP must be regained for correct synchronization
NTP diagnostic restart	Ends	NTP must be regained for correct synchronization

Warning !

In the event of an NTP problem, if you change NTP server addresses or reinitialize NTP from the NTP diagnostic Web UI page, be aware these actions cause free-run to end. This results in simulcast and

TDMA synchronization relying on NTP being correct. Before saving a configuration or otherwise re-initializing NTP, double check that you have fixed the problem with NTP in the first place.

Advice

- NTP and PPS should both be sourced locally by a GPS based timing reference at the local site.
- NTP and PPS need to have the same timebase (GPS disciplined).
- Set backup server addresses to point timing units at other sites—preferably ones with good quality links.
- Set NTP IP packet QoS to expedited.
- NTP can be distributed via site routers, but there is no particular advantage in doing that.

Synchronization Failure Modes

This table summarizes some TB7300, TB9300 and TB9400 failure modes associated with synchronization problems and NTP.

Condition	Status	Possible causes	Check
Transmit buffer alarms at one satellite	Impaired coverage at satellite	Free-run with incorrect wallclock time on satellite	NTP alarm at satellite
Transmit buffer alarms at multiple satellites	Impaired coverage at satellites	Free-run with incorrect wallclock time on master	NTP alarm at master
Simulcast synchronization alarm	Base station may not transmit (tx_when_unsync=false), or simulcast overlap failure	• Frequency reference absent or bad • 1PPS input absent or bad • NTP timing bad • Missing licenses	• Frequency reference alarm 1PPS alarm • NTP alarm • Simulcast license
P25 Phase 2 Site synchronization unaligned alarm	Base station won't transmit Phase 2 (independent of tx_when_unsync)	• 1PPS input absent or bad • NTP timing bad	• 1PPS alarm • NTP alarm
DMR receiver synchronization alarm	• Base station can receive but overlapping coverage is impaired. • Base station may not transmit (tx_when_unsync=false), or simulcast overlap failure (simulcast channels)	• 1PPS input absent or bad • NTP timing bad	• 1PPS alarm • NTP alarm

Frequency reference alarm	Simulcast base station may not transmit (tx_when_unsync=false), or simulcast overlap failure	Connector, cable, frequency reference unit	Connectors, cable, alarms on timing unit
1PPS alarm	Simulcast base station may not transmit (tx_when_unsync=false), or simulcast overlap failure	Connector, cable, timing unit	Connectors, cable, alarms on timing unit
NTP alarm	• Possible simulcast synchronization failure (if simulcast alarm present) • Possible TDMA synchronization failure (if P25 site alignment / DMR receiver synchronization alarm) • Possibly no synchronization loss (if other alarms absent)	• NTP timing inputs inconsistent with each other • Insufficient NTP timing inputs • Slow convergence to good NTP	• Run NTP diagnostic test • Run NTP diagnostic test • Restart timing on NTP diagnostic page
NTP diagnostic test reports no server selected	NTP alarm. If base station can successfully free-run internal time base, simulcast / TDMA timing should be unaffected.	• Preferred server / 1PPS missing	• Network connectivity problem / timing unit offline
		• Preferred server and / or 1PPS are falsetickers	• Fault in local timing unit • Local timing unit lost GPS
		• Backup server(s) missing	• Network connectivity problem / timing unit offline
		• Backup server(s) bad jitter or offset	• Network QoS problem
		• Backup server(s) is/are falsetickers	• Faulty timing unit / loss of primary synchronization

Notes

1. NTP uses the 1PPS input to improve the time accuracy of the server with which it is associated (on TB7300, TB9300 and TB9400 base stations that is the preferred NTP server). If the preferred server is bad (i.e. not valid or not reachable) the PPS pulse doesn't contribute to wallclock time. This condition doesn't result in a TDMA or simulcast synchronization failure if the 1PPS input is present, and NTP has a valid server, or if the base station is able to free run wallclock time.

2. TB7300, TB9300 and TB9400 base stations will free-run wallclock time if NTP loses its time source.

Reference documents

Frequency Accuracy requirements for P25 and DMR

Timing reference requirements

Publication Information

Related Documentation	None.
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Compatibility Issues	None.
Confidentiality	Confidential – This message or document contains proprietary information intended only for the person(s) or organization(s) to whom it is addressed. All recipients are legally obliged to not disclose Tait technological or business information to any persons or organizations without the written permission of Tait.
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