TERMA
ALLIES IN INNOVATION

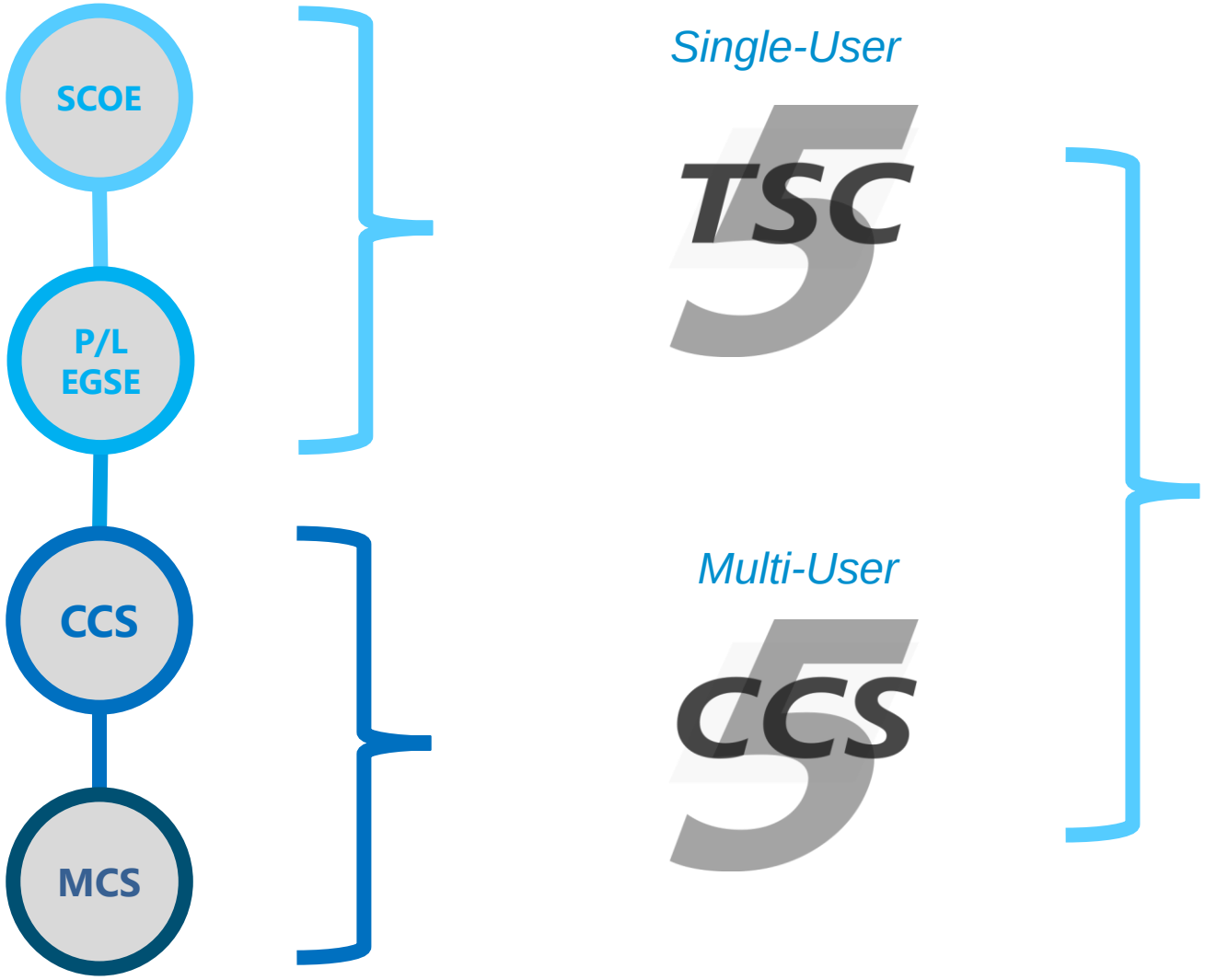
PUBLIC

13 March 2024

CCS5 & TSC

SPACECRAFT MONITORING & CONTROL SYSTEMS

Software Tools for Spacecraft Monitoring



Unified Monitoring & Control

- **data model…**
- **procedures…**
- **displays…**
- **archives…**
- **protocols & data encoding…**
- **authentication & encryption…**

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Motivations & History

Legacy systems used in European missions (e.g. SCOS2000, OC, CGS)

- maintenance increasingly difficult, becoming uneconomic, unfeasible
- flexibility & performance not enough for new missions
- installation & upgrade processes very onerous

Context:

- Adopting completely new model requires familiarization by end users
- Terma too small to set or impose industry-wide standards

Decision: fully new implementation of compatible products, using SCOS2000 MIB data model

- **TSC** = single user : Instruments, Payloads & SCOE AIT
- **CCS5** = multiuser : Satellite level AIT and Operations

Technologies: **Qt, QML, Tcl/Tk, JavaScript, NATS**

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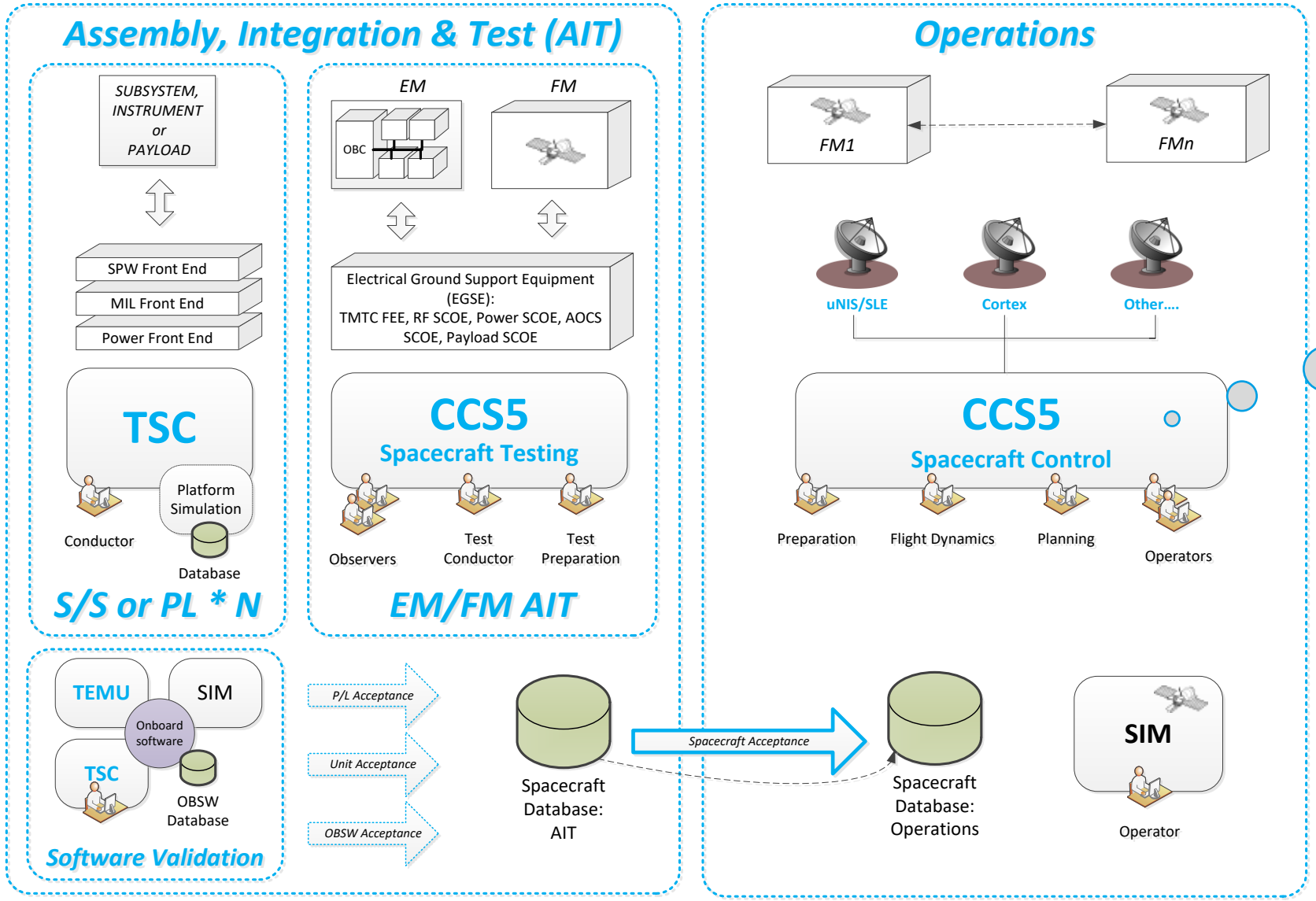
Satellite Checkout & Operations



Cloud Deployment Friendly
(Docker & Kubernetes)

Easy to Install & Set Up

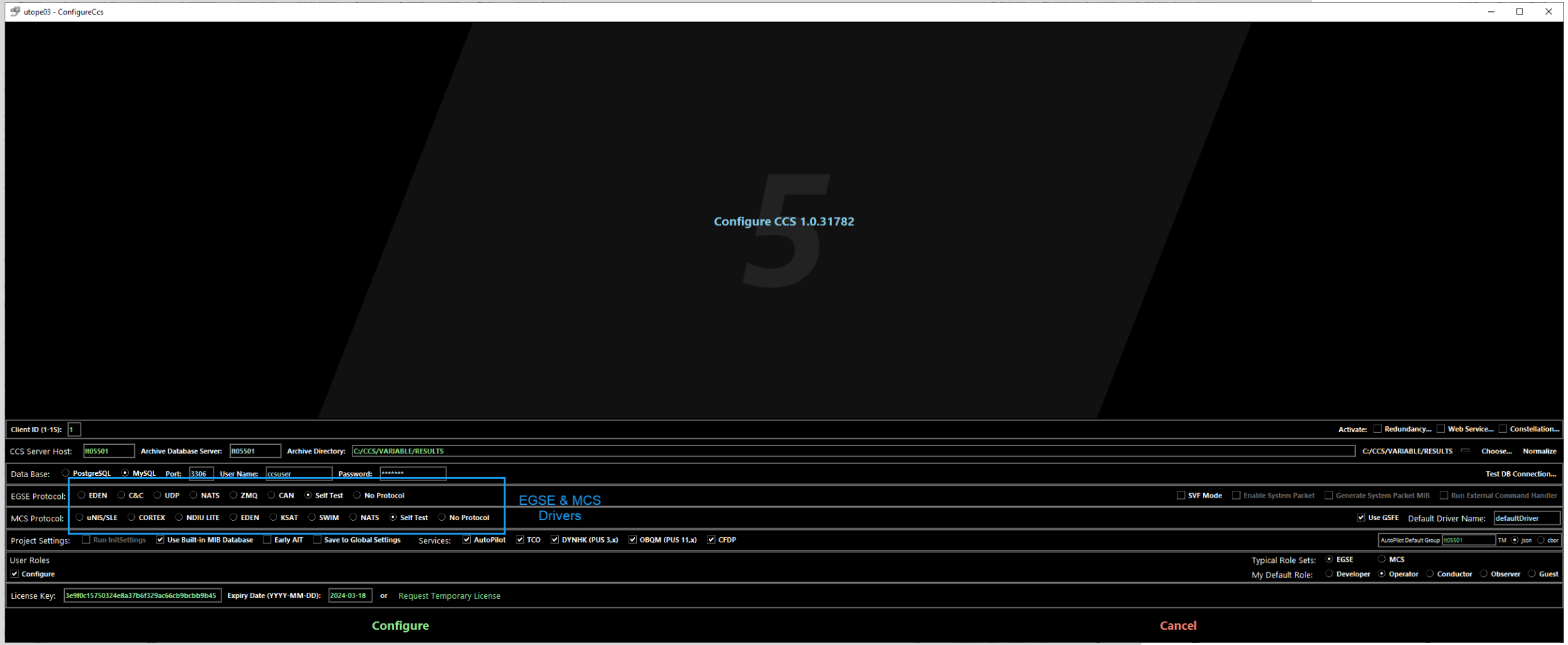
Immediate downloads for:

- Windows 64-bit (.exe)
- Linux 64-bit (.rpm)
- docker pull ccs5 <tag>

Install or Upgrade in Minutes

Configuring CCS

Simple UI for configuration choices: (protocols, databases, file locations…)



Standards Support

Fully-functional TMTC

- Follows & enhances features specified in SCOS2000 MIB (6.9+…7.2)
- ECSS PUS-A and PUS-C *(note - PUS not mandatory!)*
- CCSDS TMTC Packets & CFDP
- CCSDS TM Frames & TC CLTU, COP1
- ESA & CCSDS Authentication & Encryption
- CubeSat Space Protocol v1 & v2 (CSP)

Flexible configuration options, e.g. PUS & CCSDS options, time format…

Enhanced features, e.g.:

- Unlimited MIB field lengths
- Global support for Variable Packets and Parameters
- Deduced parameters in both TM and TC
- Fully configurable length indicators for variable-length parameters
- Different endianity support
- Automatic time stamps in TC headers
- Different synthetic (derived parameter) languages

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External Interfaces

Configurable EGSE packet level plugins (e.g.):

- EDEN Protocol
- C&C Protocol
- Serial, CAN, ZMQ, NATS, …

Protocol control & status available directly from TOPE

One EGSE protocol must be selected, they cannot be mixed in the same program

Configurable MCS frame level protocols (e.g.):

- NIS (+ optional SLE)
- Cortex
- NDIU LITE
- KSAT LITE

Low level access (e.g COP1 status) available directly from TOPE

Any combination of MCS protocols can be selected

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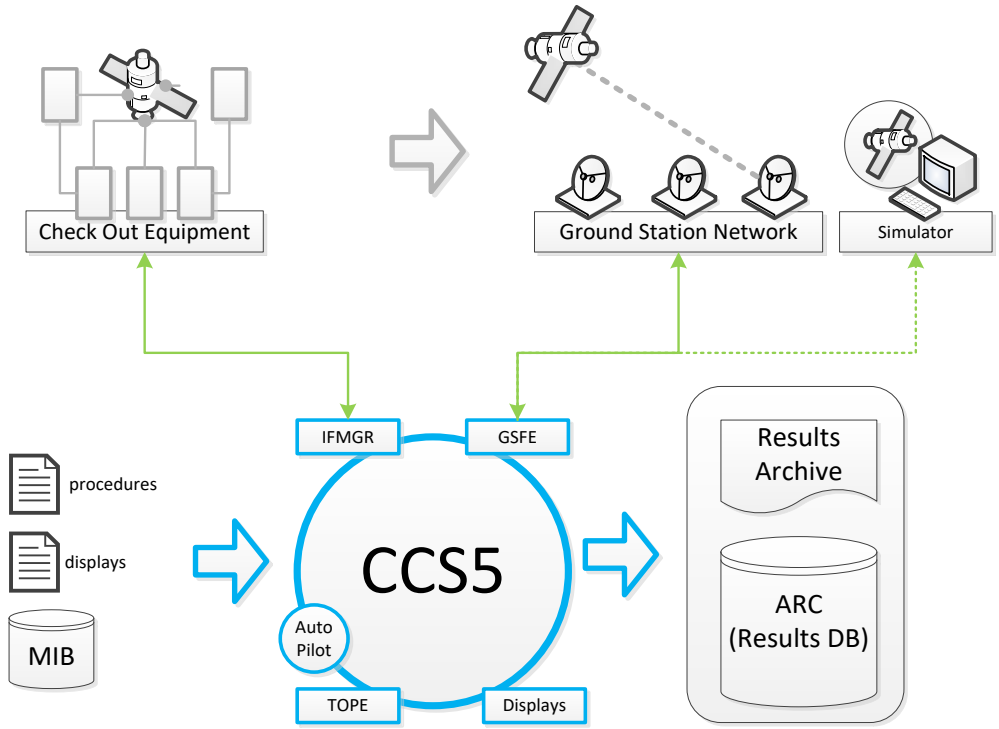
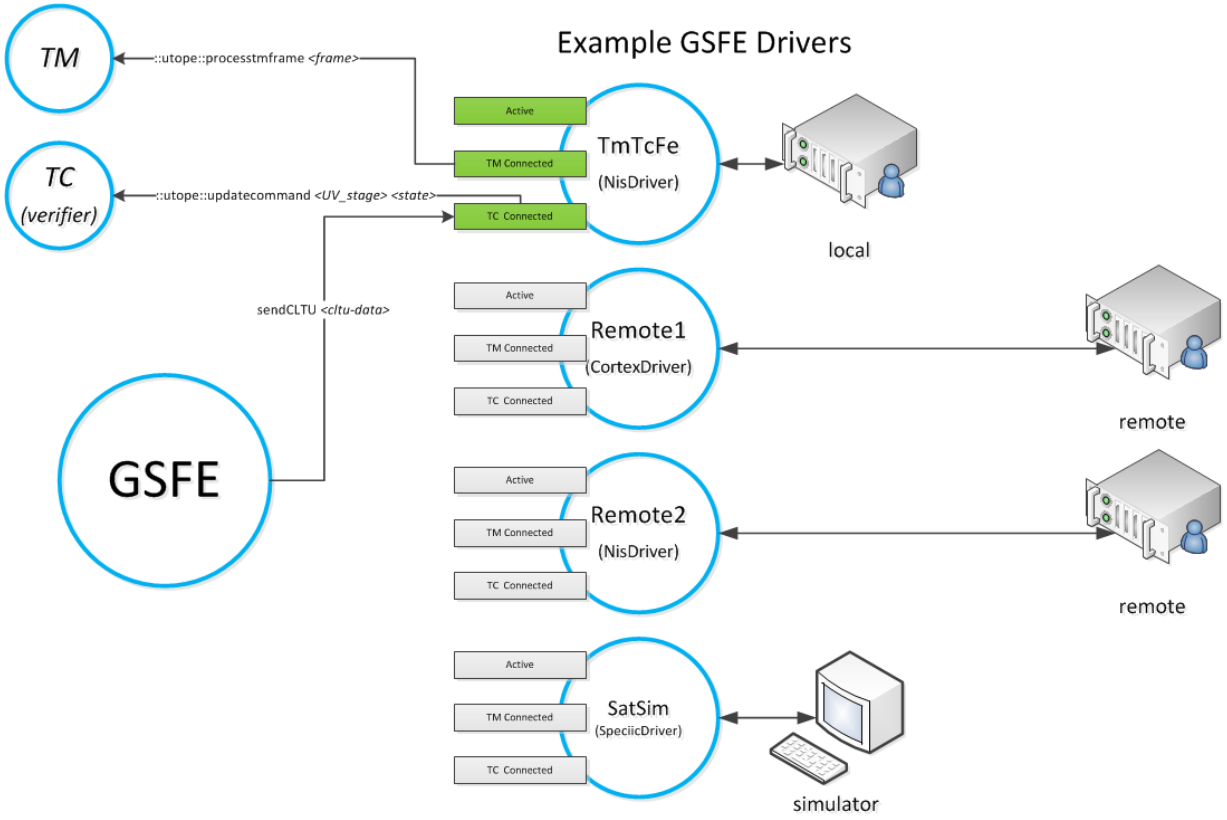
Mixed Interface Protocols



EGSE and MCS protocols can be combined

- Allows interfacing to satellite onboard computer at frame level using a modem,
- At the same time, checkout interfaces at packet level using an EGSE protocol

Example GSFE Configuration



Each external interface is a named instance, e.g. “Kiruna”, “Svalbard”, “Maspalomas” (any number)

- Protocol on each interface depends on configured driver class, e.g. “NisDriver”, “CortexDriver”, “NdiuDriver”
- Driver instances can be connected & disconnected as desired
- Protocol drivers are scripted (TOPE), so a new protocol can be implemented very quickly

Performance

Needed for…

High-rate interfaces used in EGSE (e.g. SpaceWire)

X-band & Ku-band RF data rates & enabled applications (e.g. CFDP)

Floods of errors during checkout (e.g. massive MIB errors)

Large constellations

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Maximum Performance

Data	Maximum Rate	Notes
TM Parameters	~ 150,000 update/s	With dependencies
	~ 50,000 changes/s	Archived parameter changes
TM Packets	~ 1500/s	
Bandwidth	~ 5 Mbit/s	Monitored housekeeping
	~ 80 Mbit/s	Unmonitored, e.g. large science packets
Telecommands	~ 500/s	TSC, with verification
	~100/s	CCS, with verification

Legacy systems

- Struggle to meet current performance requirements, especially in checkout & AIT
- Expensive to maintain or upgrade

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User Interfaces

Flexible displays

- Standard desktop table & tree views
- Custom TOPE Tcl/Tk user interfaces
- Alphanumeric * Mimic Displays
- Custom QML Displays
- Track

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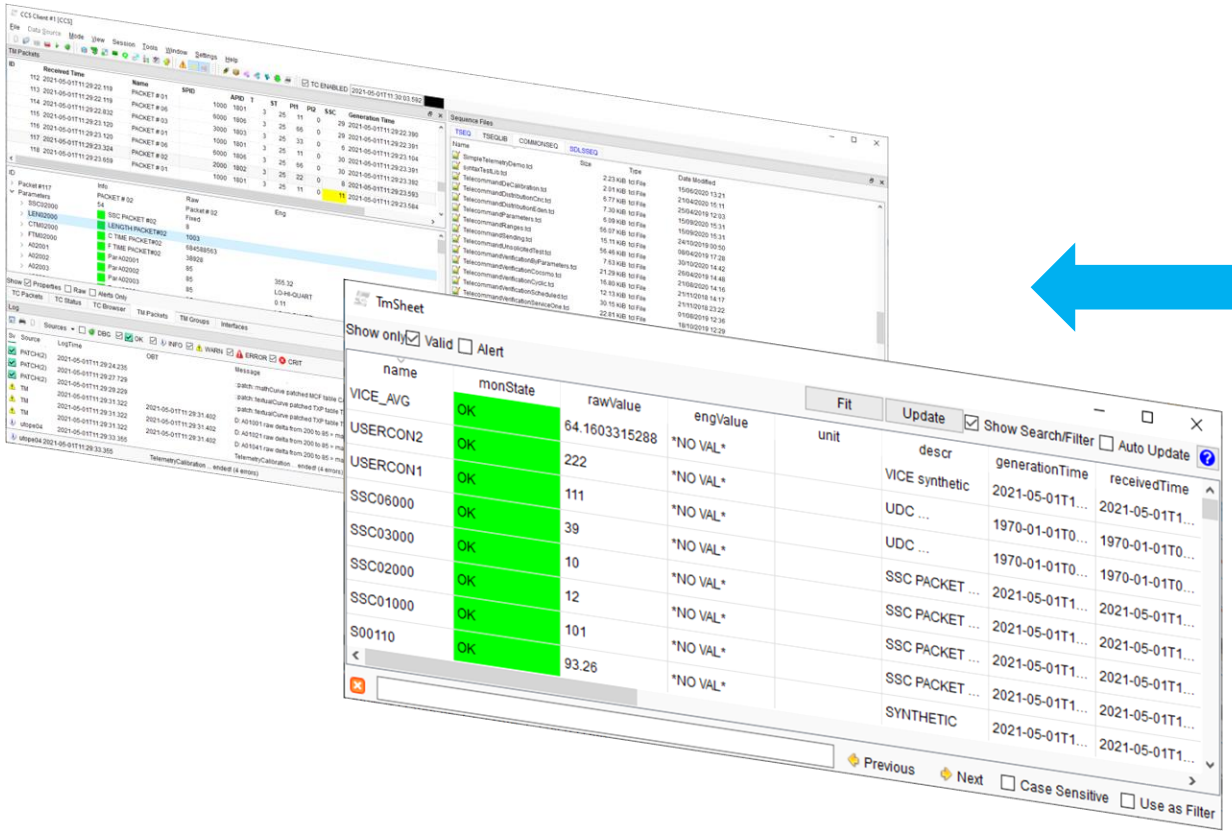
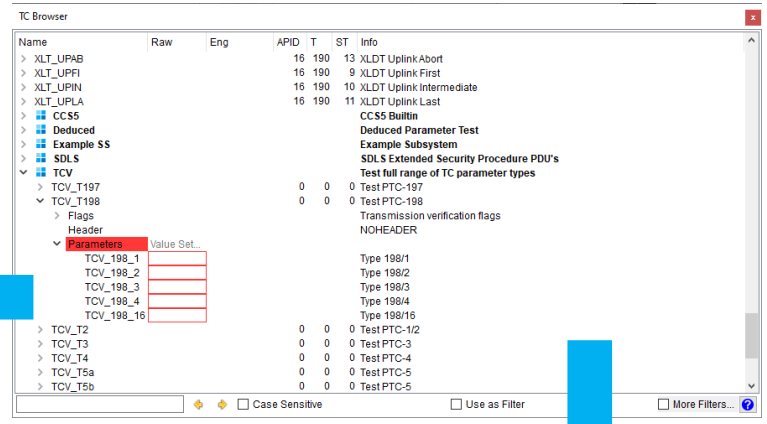
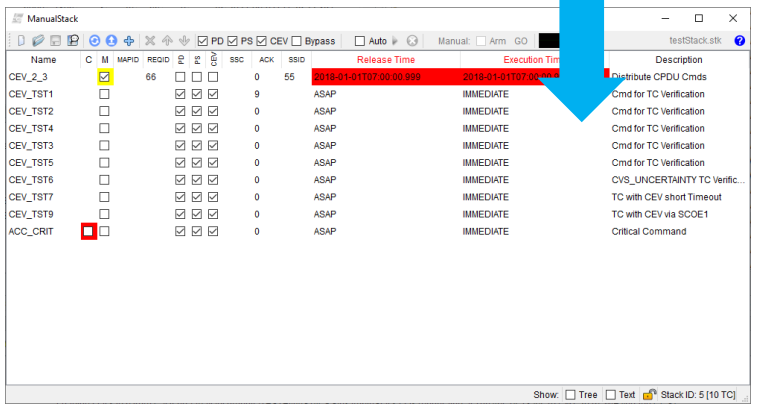
Default User Interface



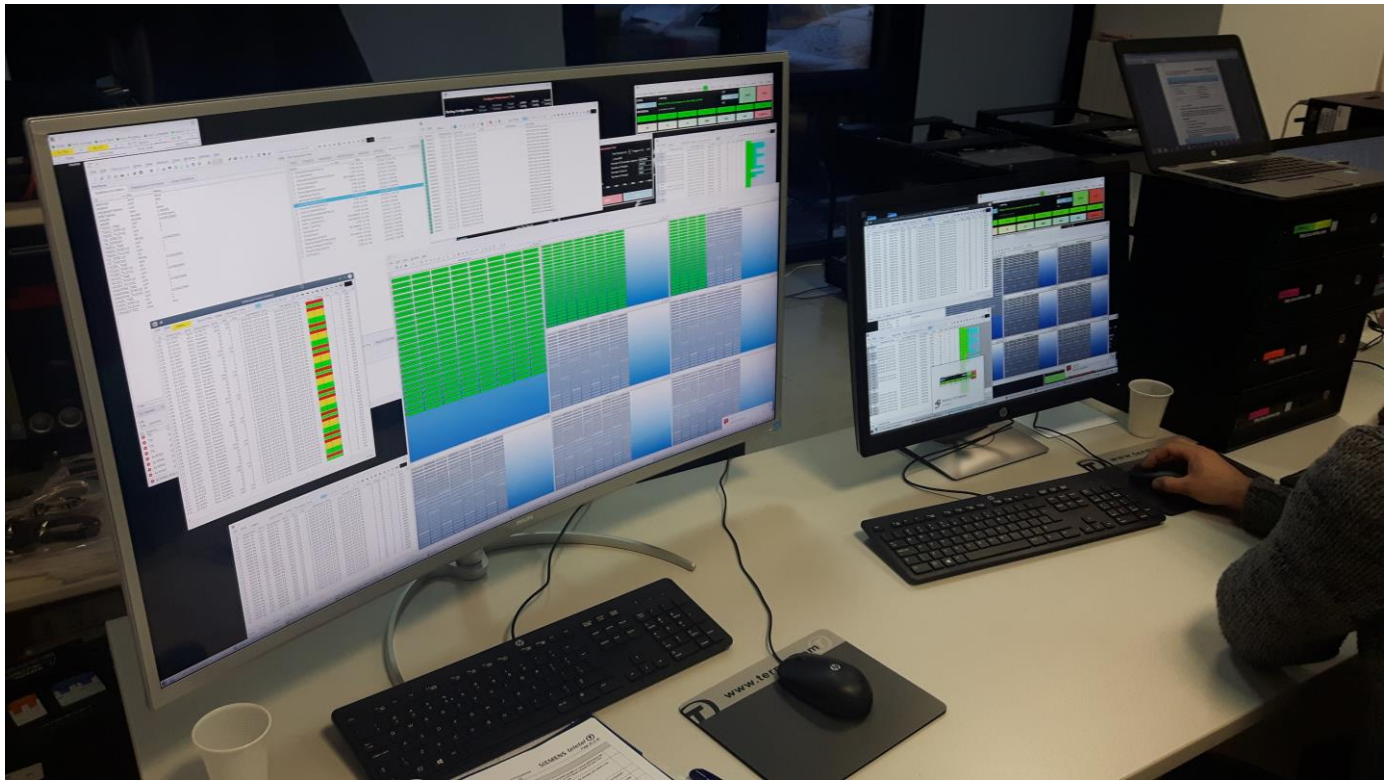


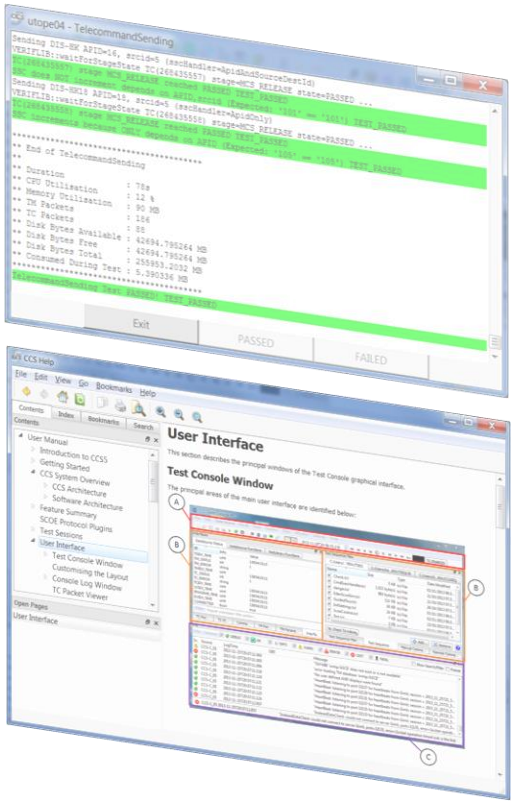


TSC & CCS console user interfaces, written in Qt/C++

- Detailed views of TM / TC packets & parameters, guided TC population
- View TOPE sequence status, enter manual TOPE commands
- Support for drag, drop, copy, paste

Default User Interface (continued)

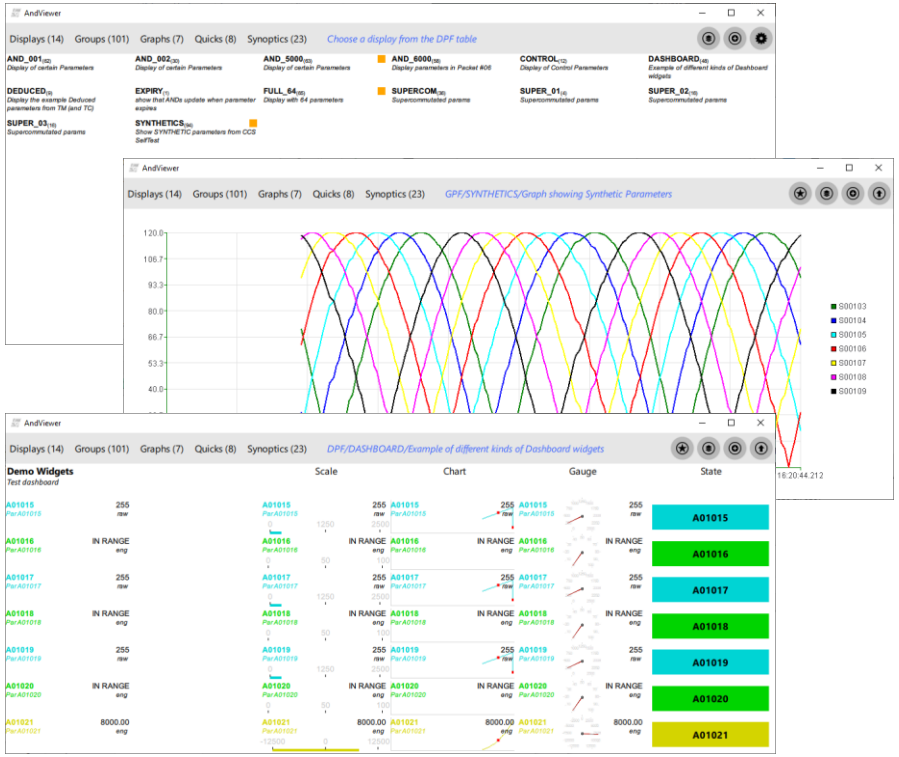




User can develop custom user interfaces in TOPE (Tcl/Tk)

- Comprehensive, indexed, context-sensitive online help
- Custom theme (colours & widget styling) can be applied instantly to all windows

Alphanumeric Displays



Light theme

Dark theme 4 x 4

Add new parameter & widget manually

Alphanumeric display is a simple tabular view of TM parameter values and states

- Tabular views & dashboards of different widgets, graphs and mimics, N x N view, …
- Fluid animation, touch enabled (written in user-visible QML, can be customised by end user)
- Allows dynamic creation of new displays, or adding parameters to existing ones (drag & drop, or one by one)
- Includes groups, graphs, custom QML & mimic displays

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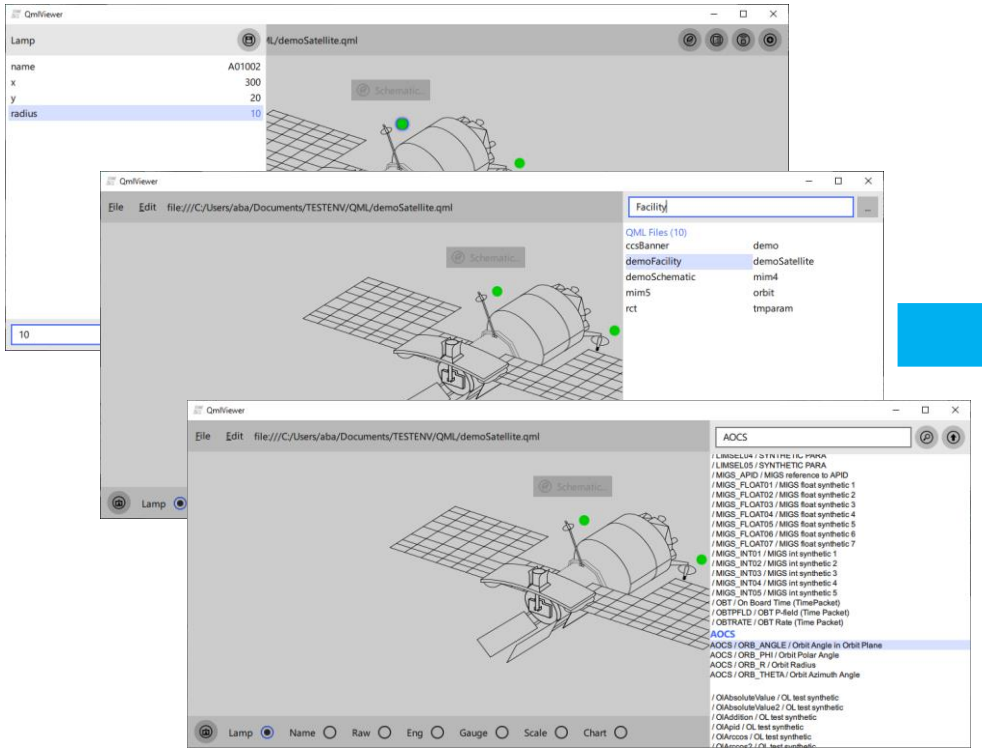
Mimic Displays



Mimic editor, light theme

Simple MIMIC (schematic displays)

- Set background image or SVG vector graphic (e.g. from Visio or Inkscape) and position animated objects over it
- Double-click or drag & drop to add TM parameters
- Add links (to other pictures), buttons for TC stacks and Sequences
- Animate in AND viewer, PAR history & AP display (also possible to embed Mimics in custom QML displays)

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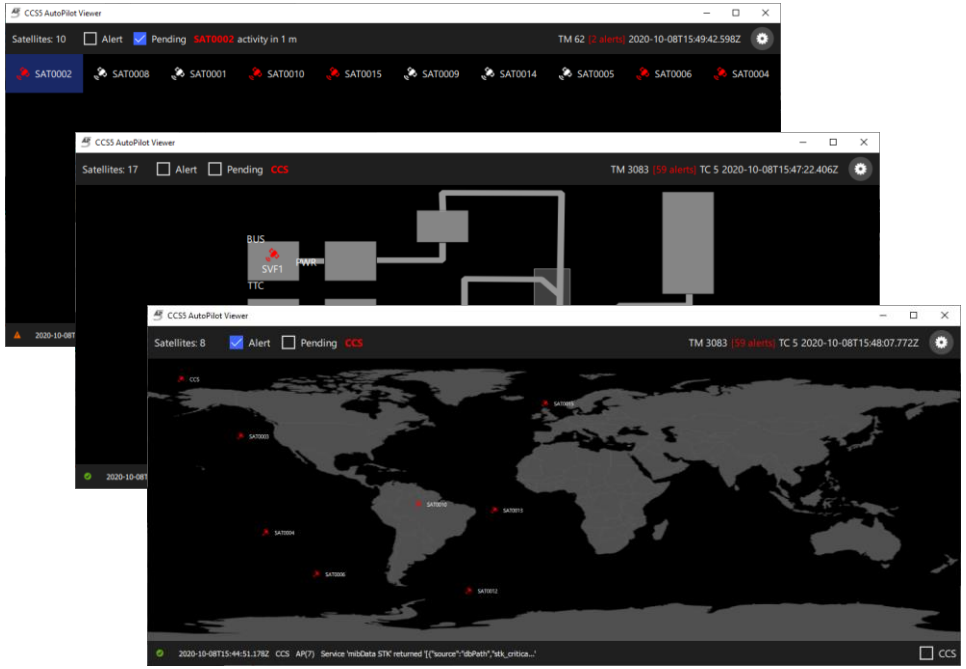
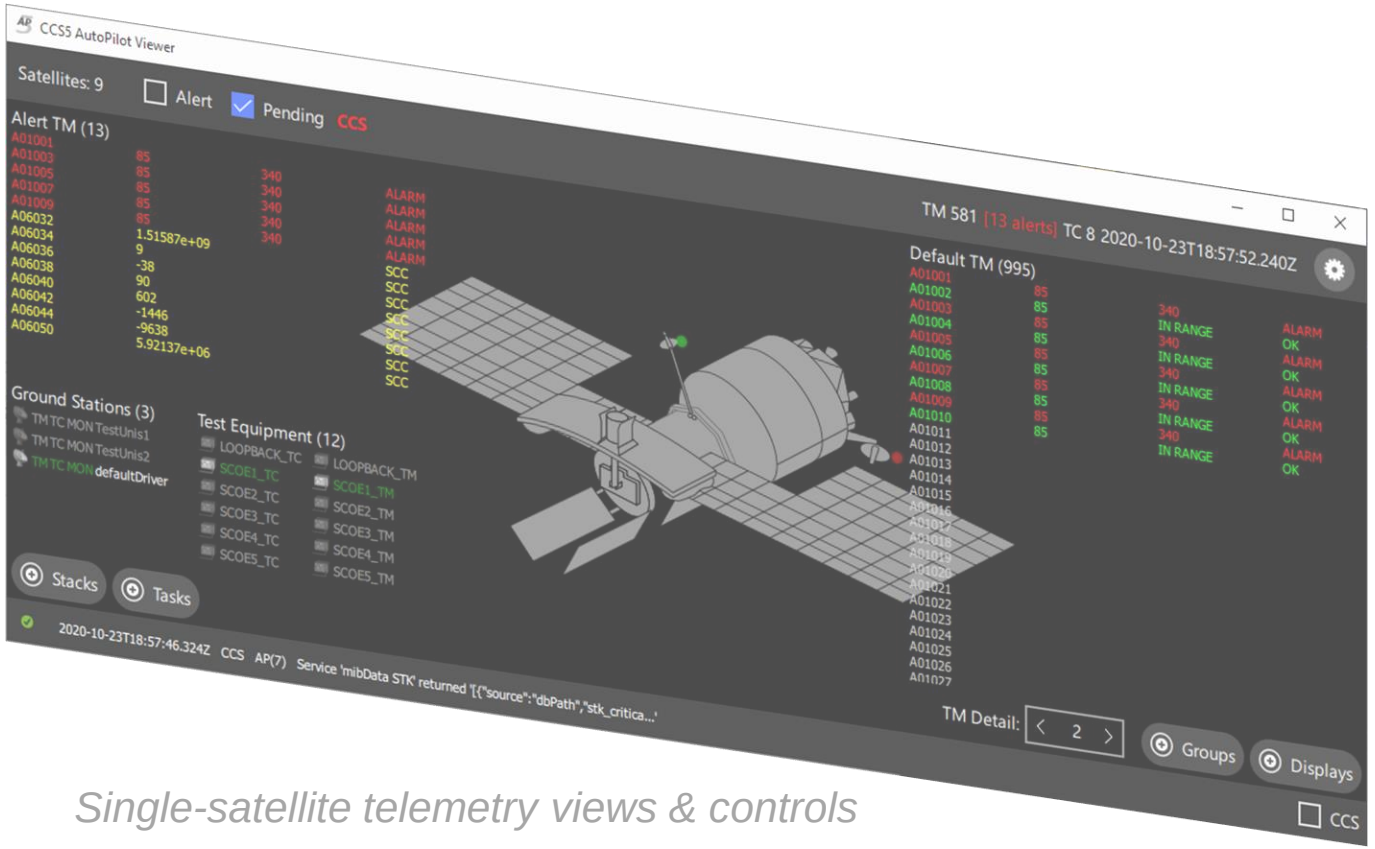
AutoPilot (AP) Fleet Viewer



Multi-satellite (filtered) fleet status



Single-satellite telemetry views & controls

Independent of CCS5, relies only on dynamic information from **AutoPilot** via publish/subscribe messages

- Provides overviews for single-satellite or constellations, checkout (AIT) or flight (OPS), fleet may be diverse satellites
- Provides sorting & filters for satellites, e.g. in alarm or with action pending in next time period
- Focus on single satellite: browse mimics, alarm TM, default TM, or specific groups & displays
- Allow operator to perform simple high-level, tested, permitted actions – run TC stacks or automation sequences

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Custom QML Displays

(images courtesy & © GISTDA, SSTL)

Allows development of advanced user interfaces (e.g. inspired by sci-fi movies)

- Requires QML scripting, note: results depend on effort invested!
- System provides QML modules to access TMTC data
- Show in TSC/CCS console, or in a separate application

TGSS: Terma Ground Segment Suite

CCS5 & TSC are part of **TGSS** suite of products

Covers full range of satellite testing, operation & simulation applications

See support site: https://tgss.terma.com

The next slides cover the products typically used with CCS5

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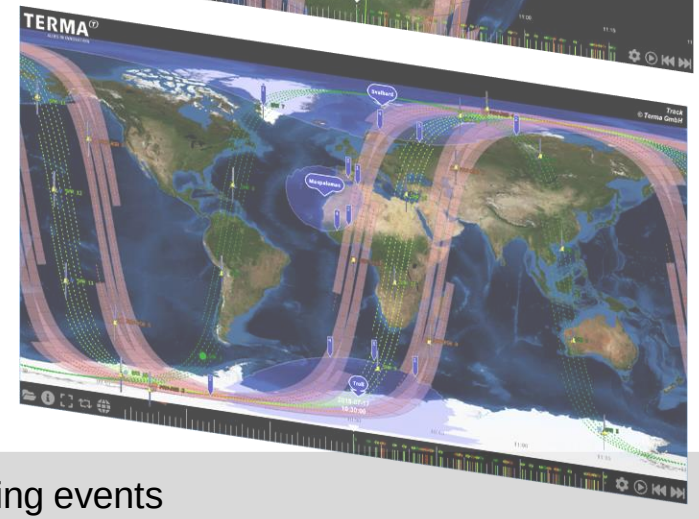
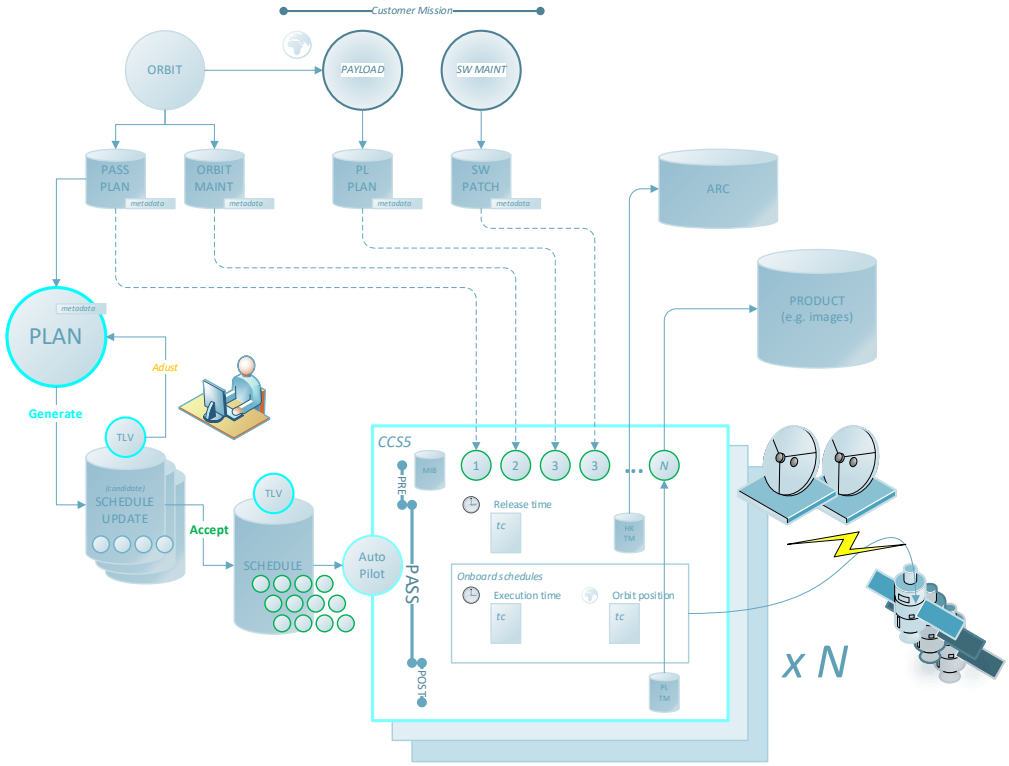
TRACK: Orbit Visualisation

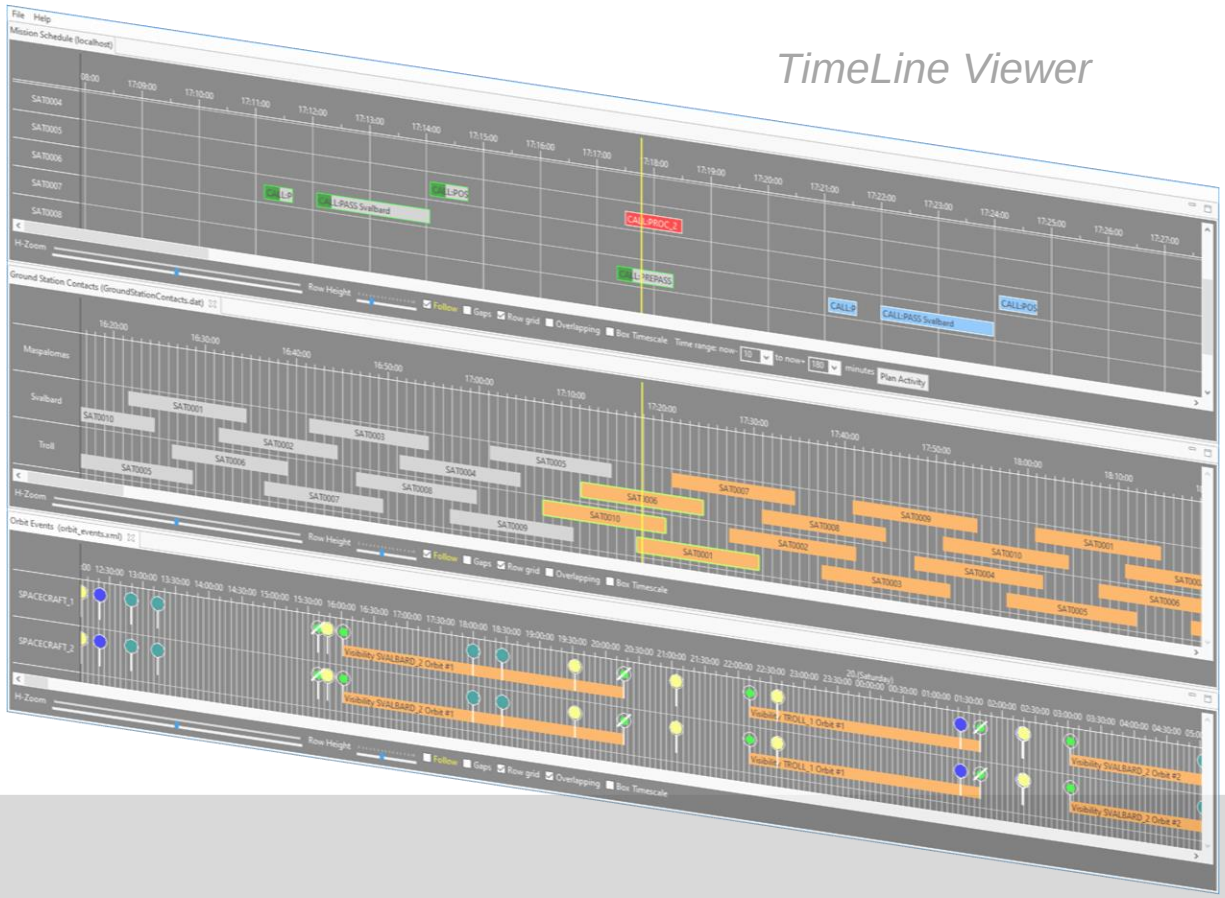


Presentation of orbit in 3D with call-outs for satellite & data links status, forthcoming events

- Accepts live TM updates from CCS/TSC as well as replay from files
- Orbit event (AOS/LOS at ground station, eclipses) & swath visualisation
- View single satellite or complete fleet, in various projection

PLAN: Mission Planning & Scheduling



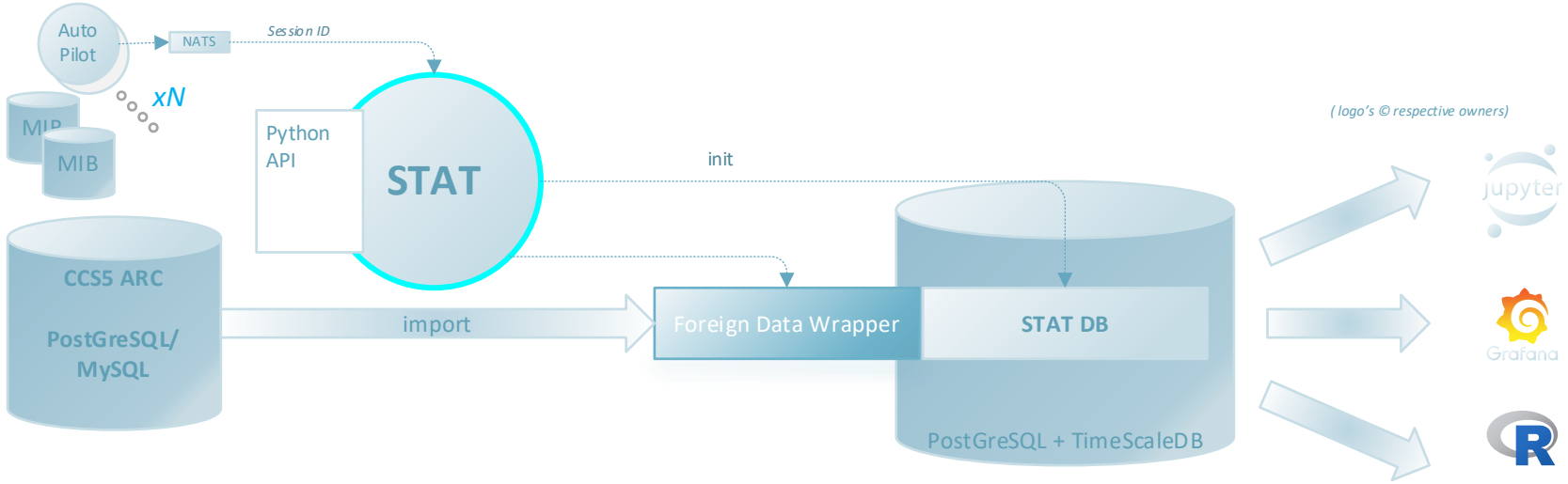


Generic automated search for acceptable schedules

Arbitrary resource definition

Visualisation of schedules in dedicated timeline viewer

STAT: Long-term Archiving & Visualisation



Grafana Dashboards

Optimised automated transfer of CCS5 TM parameters & events
Long term (compressed) archive for efficient retrieval
Variety of retrieval tools for analysis & visualisation
Interfaces to other TGSS products

Constellation & Fleet Support

Issues considered:

Support for multiple spacecraft in one host

Fleet may be homogeneous (identical, similar), or all different

UI design for managing large fleets

Avoid complex IT setup, preserve easy installation & configuration

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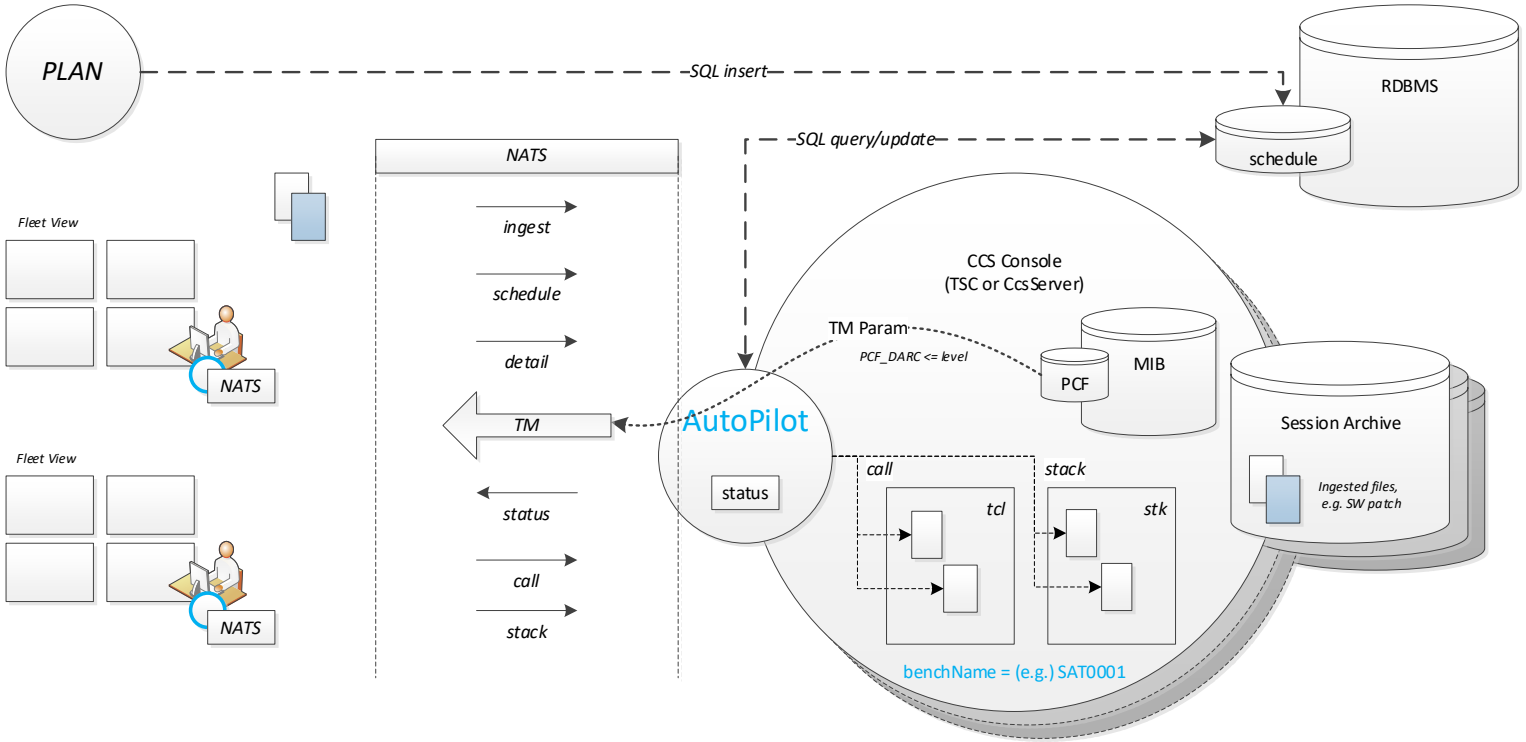
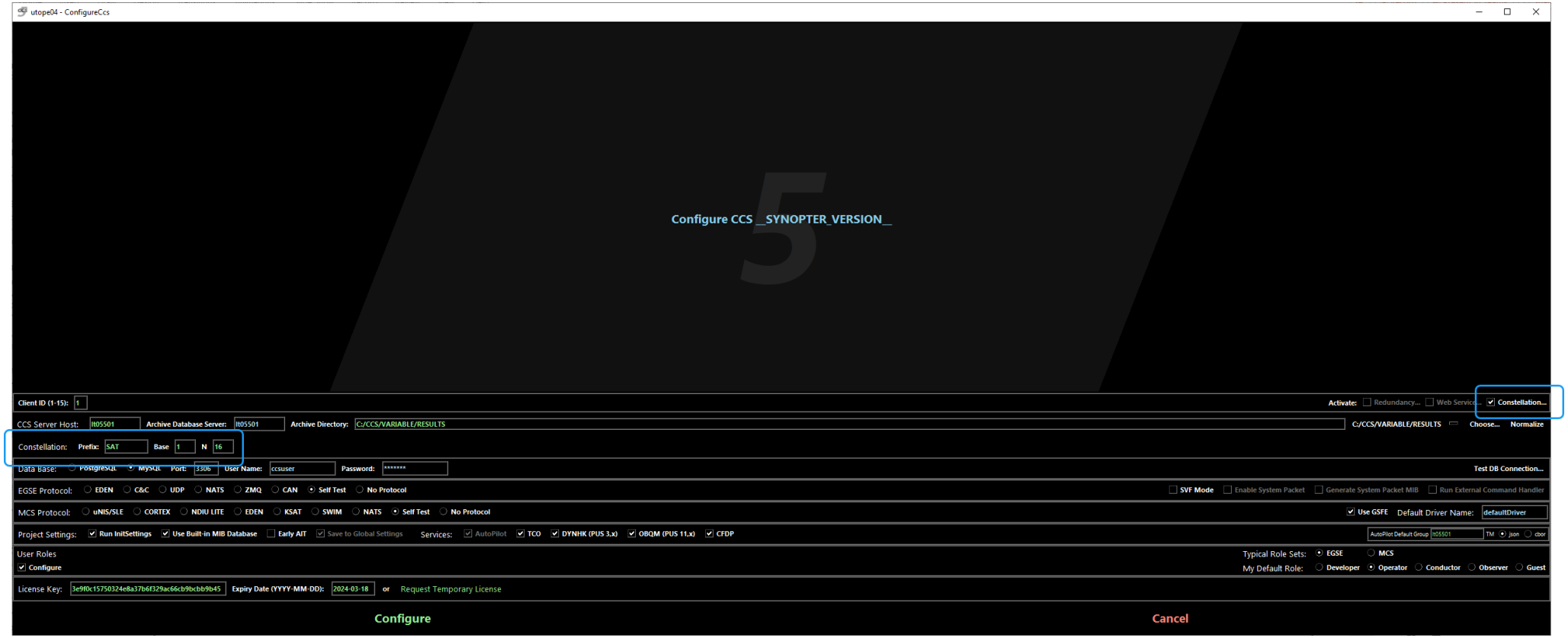
CCS5 AutoPilot



AutoPilot supports **secure** remote monitoring & control, automation & scheduling

- Single-satellite and constellation compatible, checkout or operations
- Simplified API via publish/subscribe messages (NATS) containing JSON or CBOR
- Interface is used by other Terma applications, e.g. AP viewer, TRACK, PLAN, … API also available from Python
- AutoPilot schedules planned activities and executes them, reporting the result

Constellation Configuration



- Preserves speed & simplicity of installation:
- Install, configure, click constellation option, start
- Configure S/C name, and base, and number desired
- Configure up to 9999 (maximum per VM host if deployed natively = 64, cloud = unlimited)
- No TCP/IP ports (only NATS) simple host & license setup

Constellation Deployment – Native VM's

Cluster of VM's used for large constellations

- E.g: 4 VM, 50 small S/C per VM = total 200 S/C
- One fully independent TSC for each S/C, N instances within each VM
- Archiving to single common RDBMS, CCS HIST viewers available
- Management UI either per VM or over whole cluster

Minimizes: CPU / Memory of a single server

- Standard "retail" hardware or cloud VM
- Keeps platform costs under control

Minimizes: IT, installation and setup complexity

- One VM = one system, configured once, one IP address
- Avoids allocating N x different sets of IP ports for different S/C
- Keeps IT and engineering costs under control

Maximizes: flexibility

- Within 1 VM, N x S/C are similar but can be completely different
- No fixed number of operator consoles
- Constellation lifetime may be for decades; it will evolve

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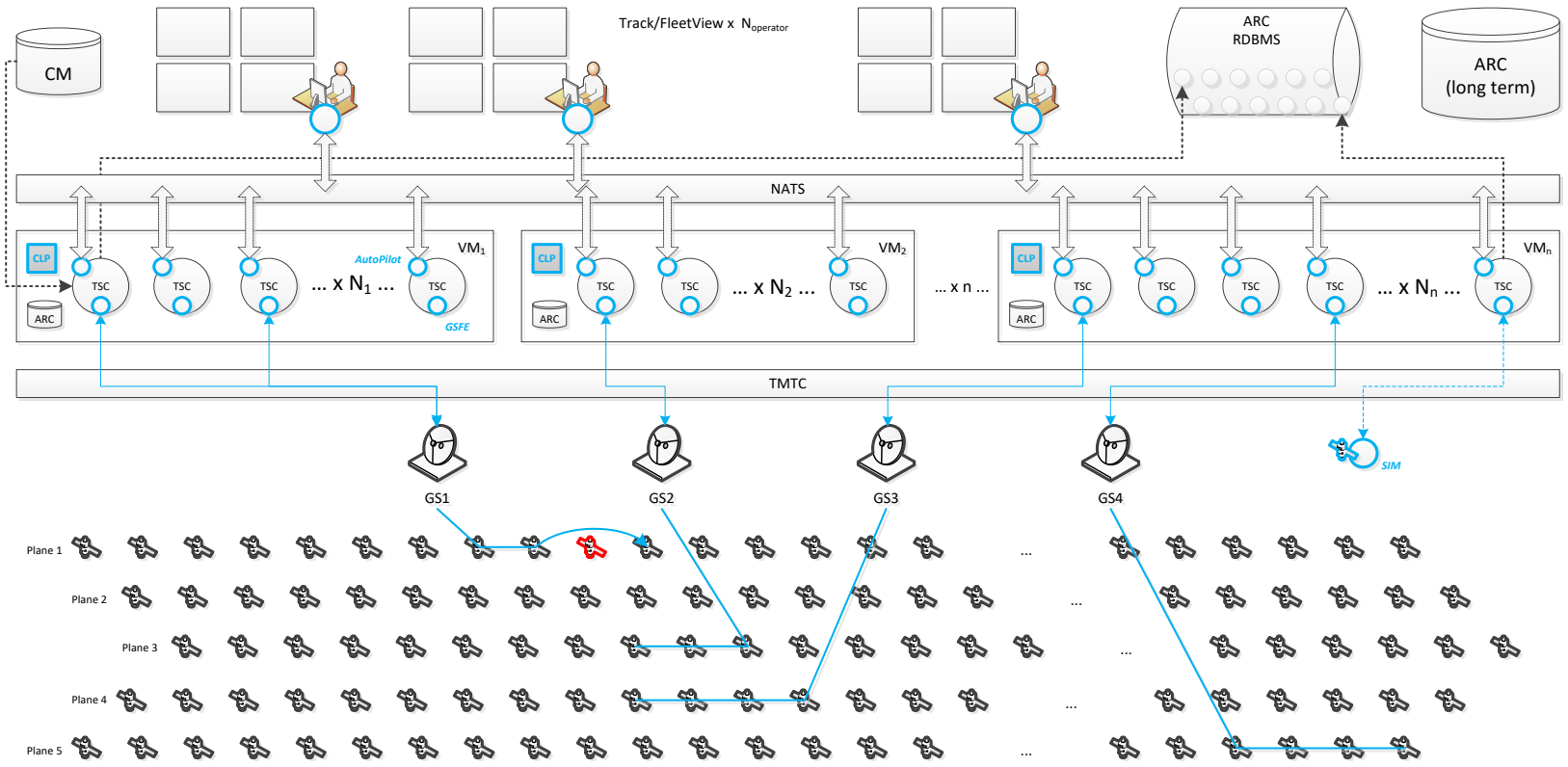
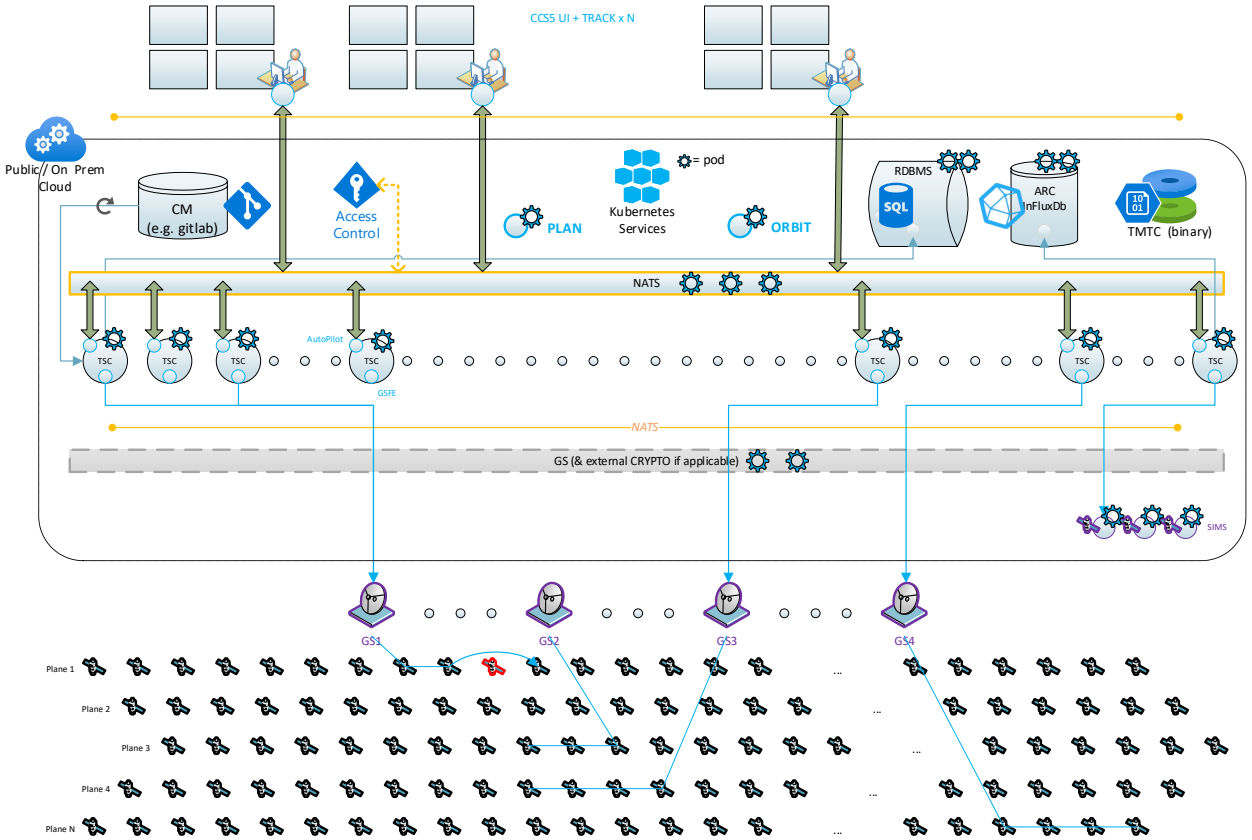
Large Constellation Example



Arbitrary number of S/C per VM, arbitrary number of operator WS

For small S/C, moderate TM/TC rates, consider e.g: 1GB RAM, 1 vCPU per S/C

Cloud Deployment



Arbitrary number of S/C, no implicit link to VM, arbitrary number of operator WS

Kubernetes, allows health monitoring, automated migration, restart & load balancing

Suitable for public & on-premises cloud deployment, 3rd party tool manifests derived from standard Helm charts

Docker container repository available to licensed customers

Integrations with 3rd-party ground network providers

Automation (TOPE)

TOPE : Test & Operations Procedure Executive

Based on Tcl/TK – graphical MMI, numerous plugins

Expressive, robust, good performance, true multi-threading, easy to learn, well-documented

Support tools: debugger, syntax checker

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TOPE Detailed Features

Syntax and basic commands derived from SCOS2000 TOPE

- Send TC, fetch & subscribe to TM parameters & packets, …
- Start & control status of TOPE sequences
- Shared variables

Numerous enhancements, e.g.:

- Full control of starting & stopping sessions
- Direct access to all properties of archived objects (packets, events)
- TM packet simulation
- TC subscription, modelling
- Detailed control of COP1
- Local packet extraction
- Full access to frame-level coding & decoding

Note: main difference when migrating from SCOS2000 TOPE is increased speed

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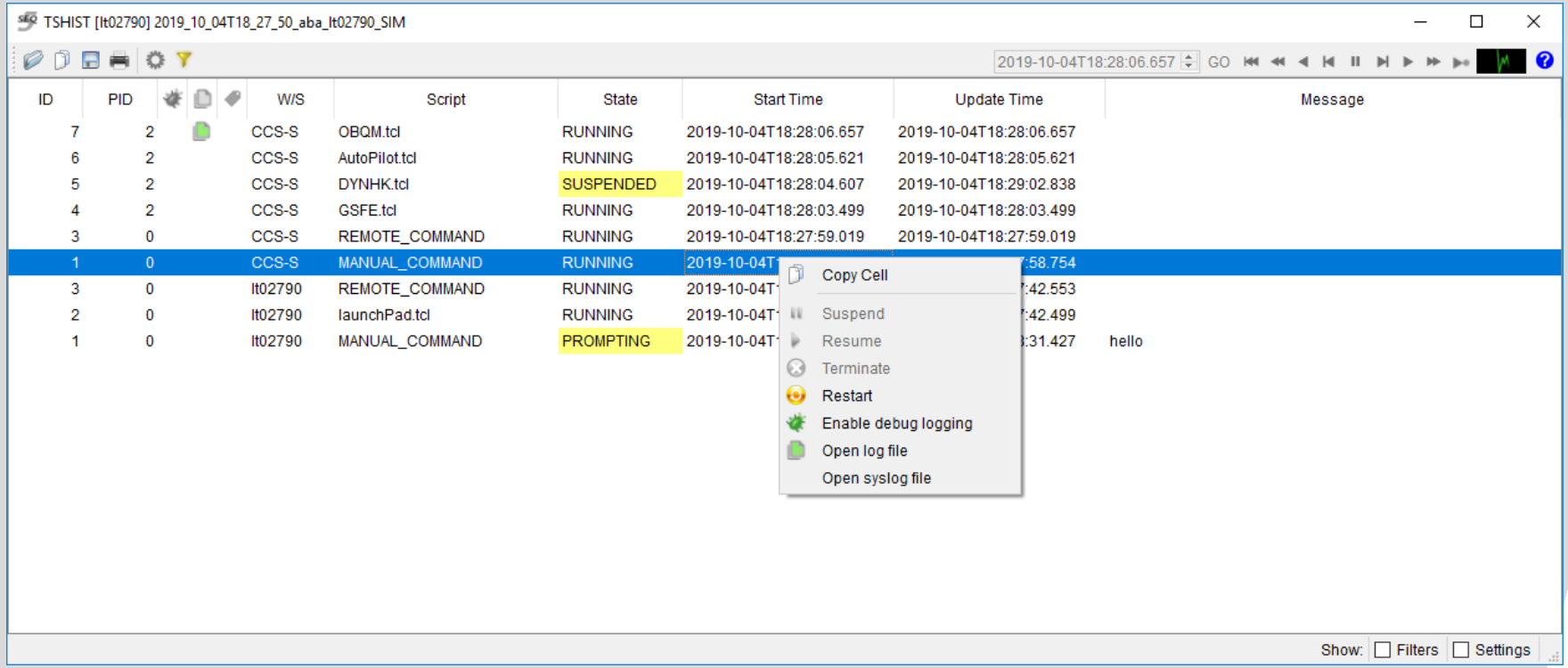
TOPE in CCS

Global status of all sequences in the whole system

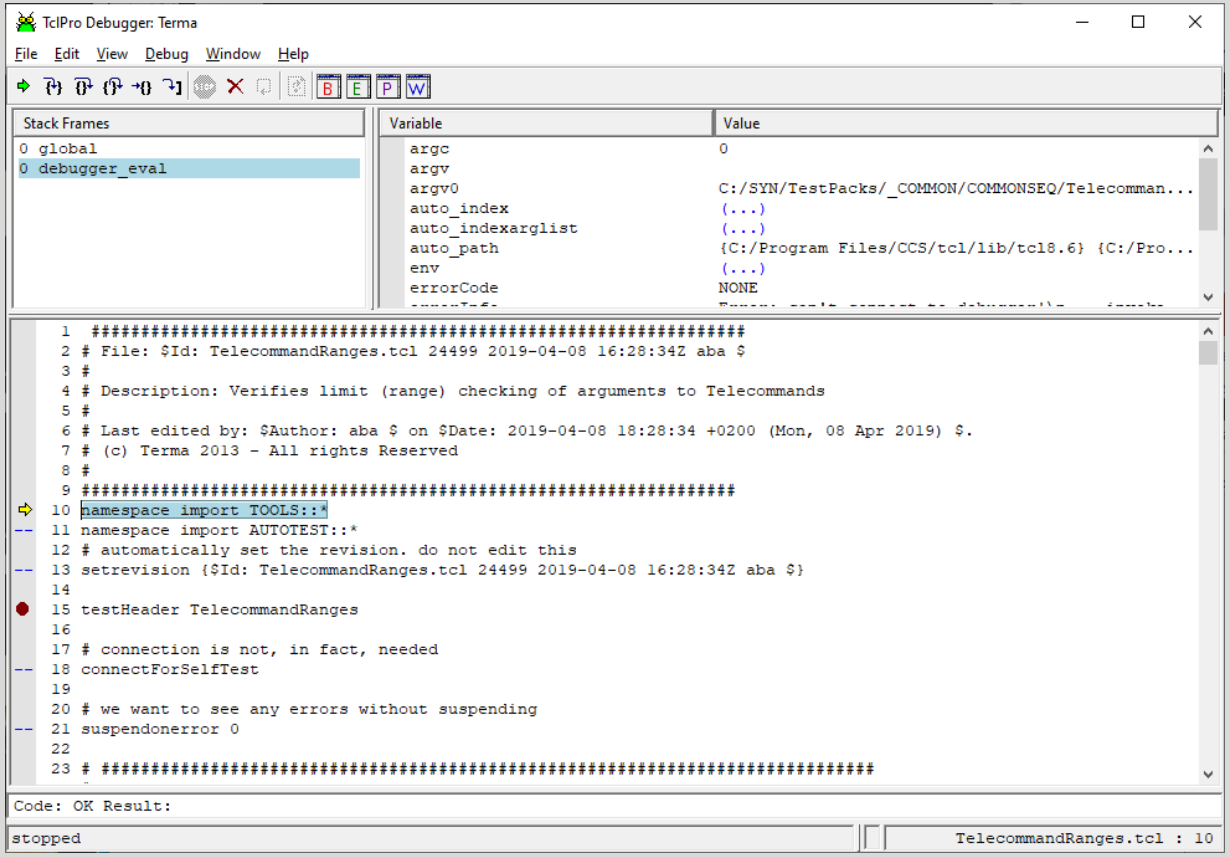
- Sequences can be manipulated
  e.g. suspended, resumed, restarted – if permissions allow it
- Actions distributed, including responding to prompts



TOPE Debugger

Visual debugger for TOPE

- Set breakpoints
- Examine & set variables



Archive Access & Retrieval

Different ways to access the CCS archive

- CCS history browsers
- Retrieval from TOPE scripts
- Retrieval tools
- Backup and restore tools

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Archive Technical Details

Indexes stored in an RDBMS :

- Choice of MySQL, Maria DB, PostgreSQL *(note - TSC uses SQLITE)*
- Enables searching for records using plain SQL
- Easy to integrate with other systems & languages (PHP, Java, Python, …)
- TM parameters stored on change

Raw data stored in segmented binary files:

- Header contains “properties” (Qt serialised data format)
- Body contains raw packet
- Nanosecond time stamp resolution
- Every TC stage recorded (detailed history of TC verification stage timing)

Live data signaled via “HeartBeat” datagrams (via NATS message broker)

- No “round robin” distribution to client applications
- Client applications can skip records if data arrives too fast
- Raw file access benefits from OS file system optimization (buffer cache)
- System relatively unaffected by addition of new clients

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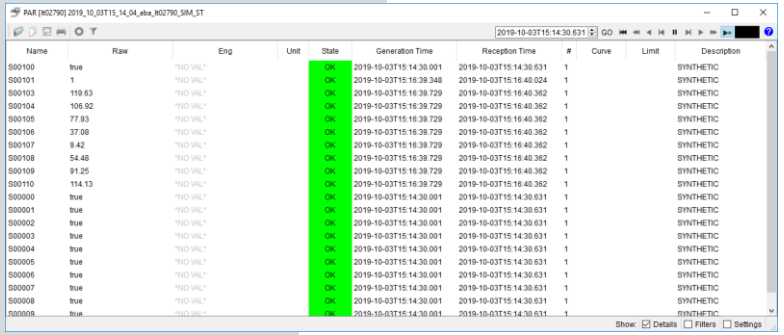
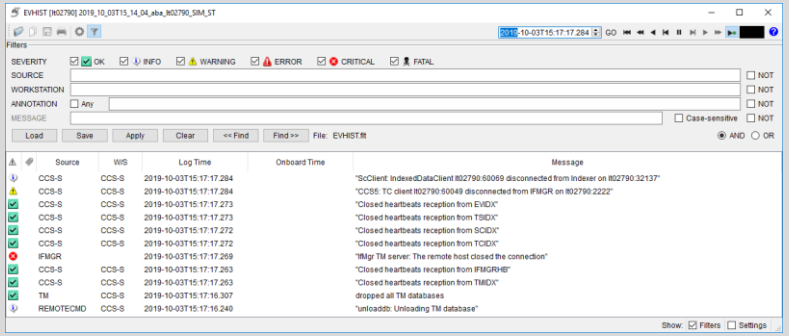
CCS History Browsers

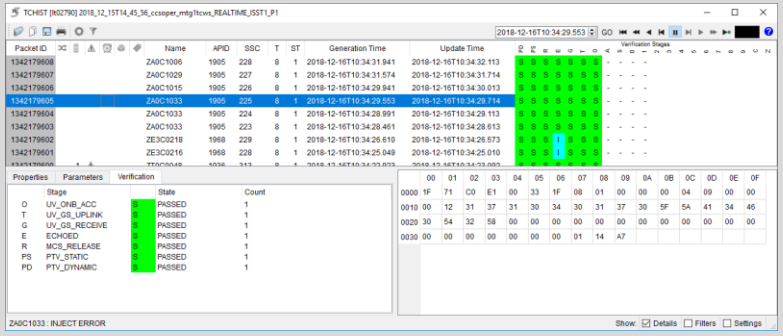
Open any session, live or not,

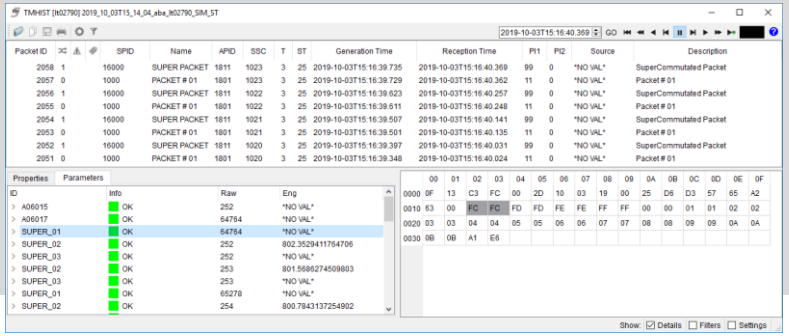
- View live status or browse history *(note CCS does not have to be running)*
- Packets (TM & TC) including parameter values & locations
- Events
- TOPE sequence live status & history
- TM Parameters, using AND & graph display definitions

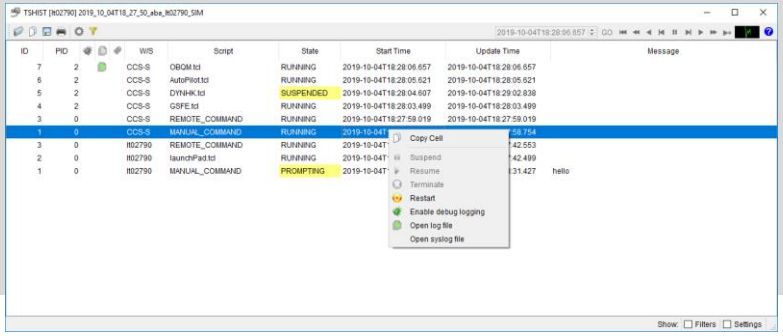
Information is derived from archive *(note independent of MIB)*

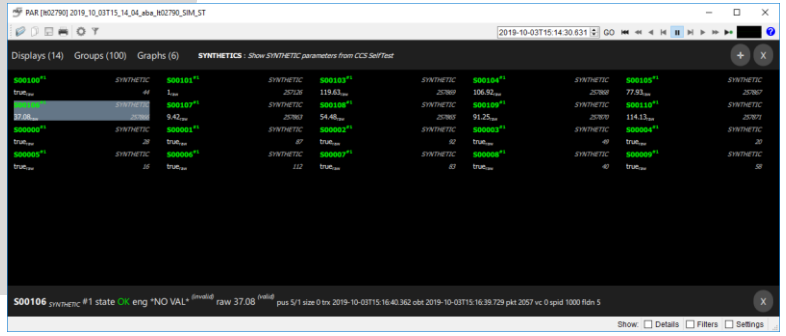










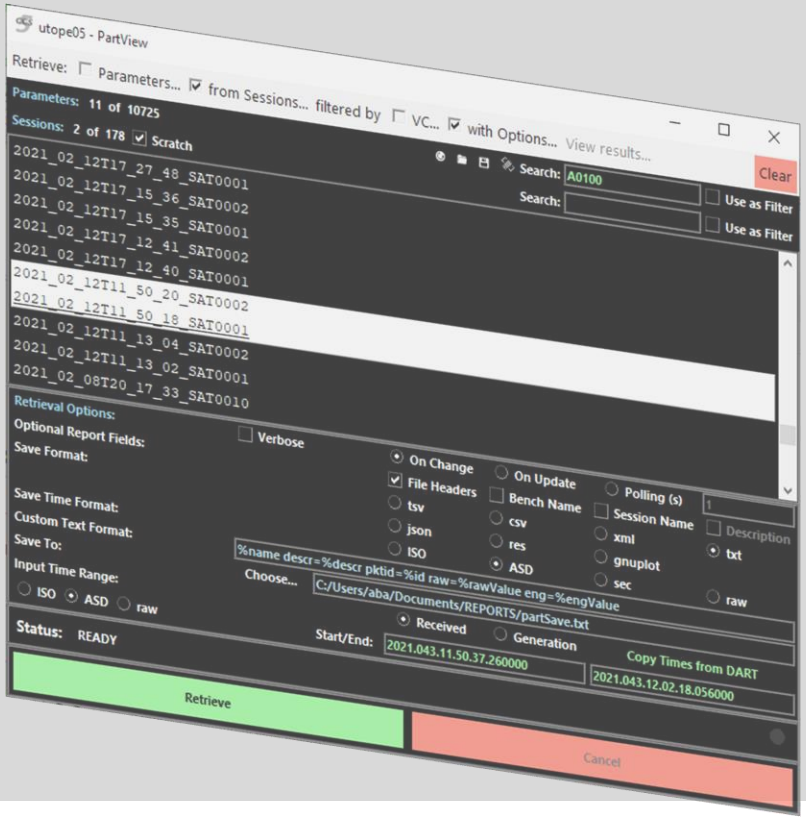


CCS5 Archive Retrieval Tools

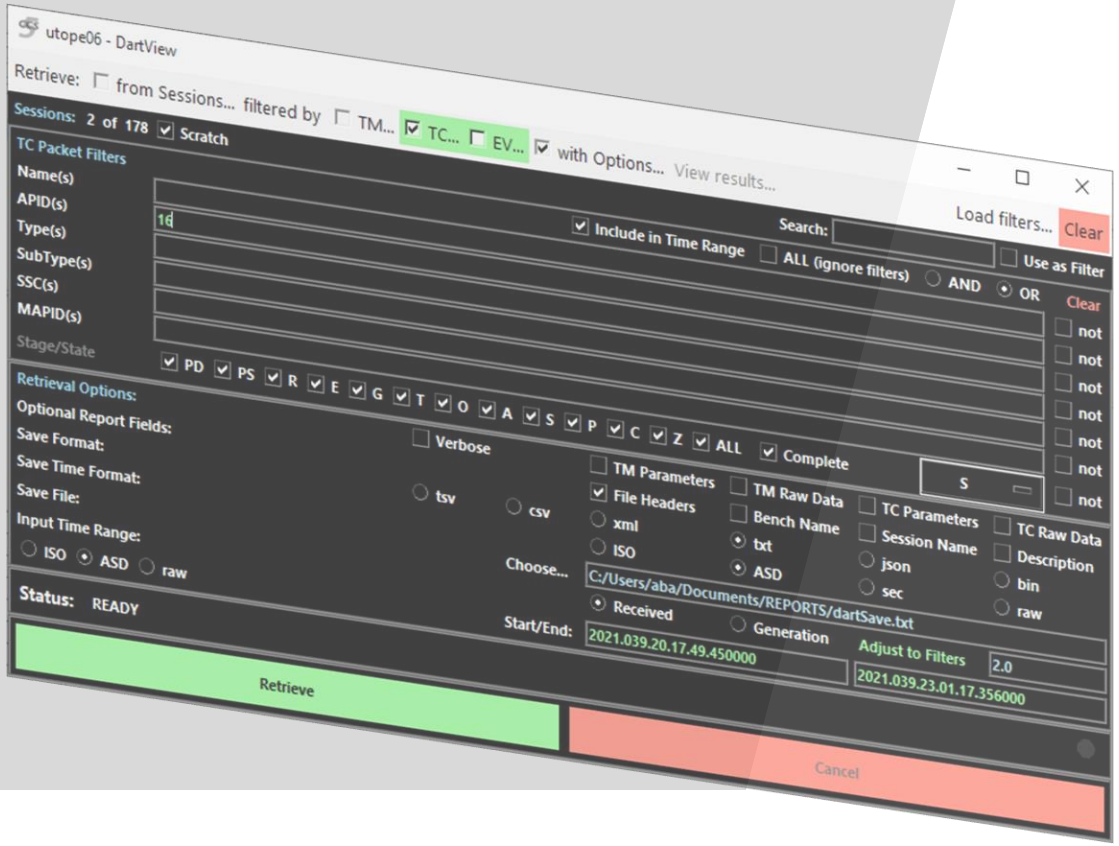
Configurable output formats *(e.g. tsv, csv, xml, txt, json)*

- Retrieve filtered requests across several sessions
- No need to start CCS
- Retrievals can be called from TOPE

PART / TM Parameter Retrieval



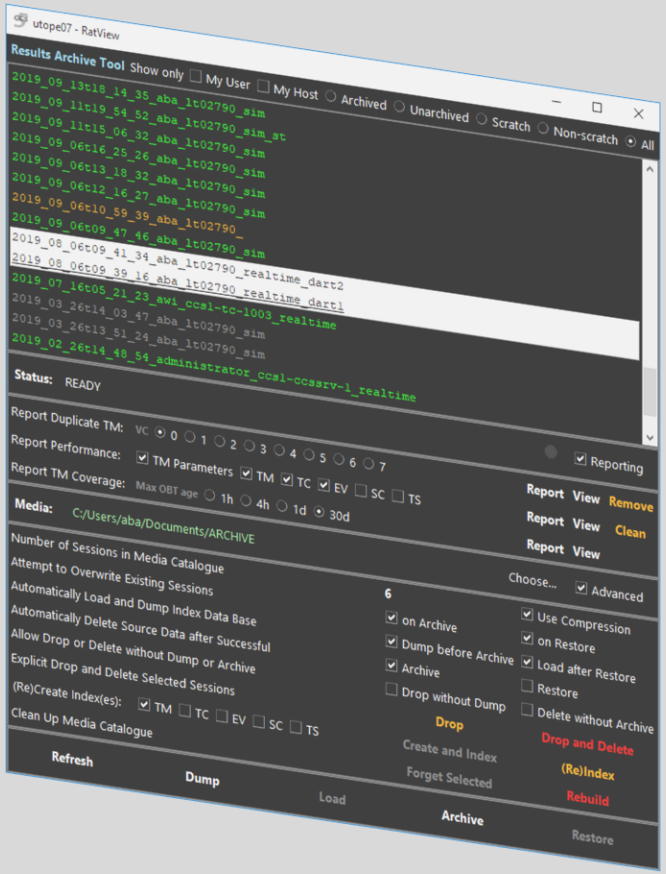
DART / Mixed Data Retrieval

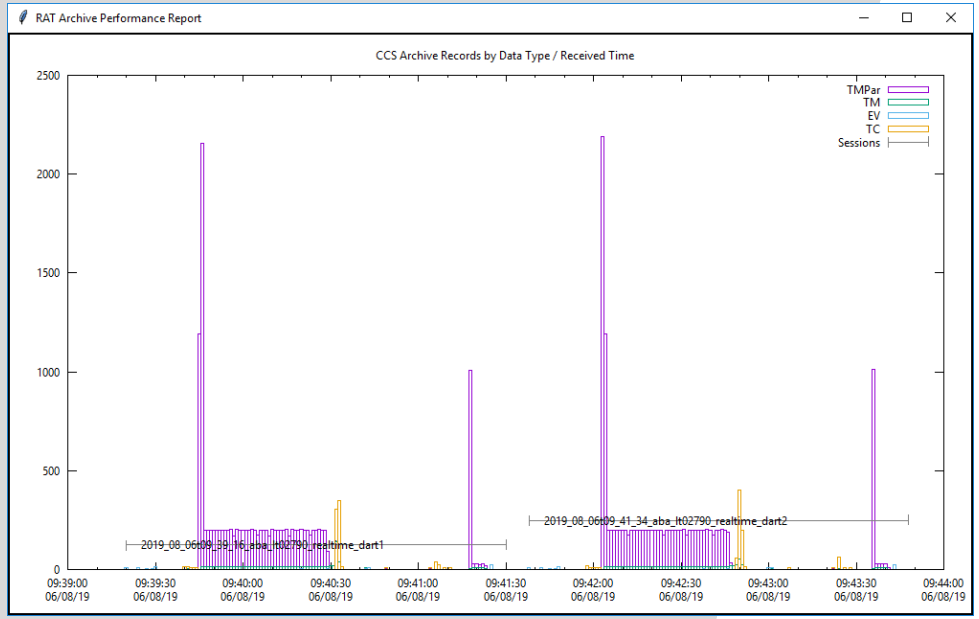


CCS Archive Session Management

RAT : Results Archive Tool

- Manages backup & restore of CCS sessions
- Supports generation of session reports
- Actions can be automated from TOPE





Special Features

Add flexibility for test & operation phases

Standard features mimic behaviour of ESA SCOS2000

Additional features motivated by experience during AIT & customer requests

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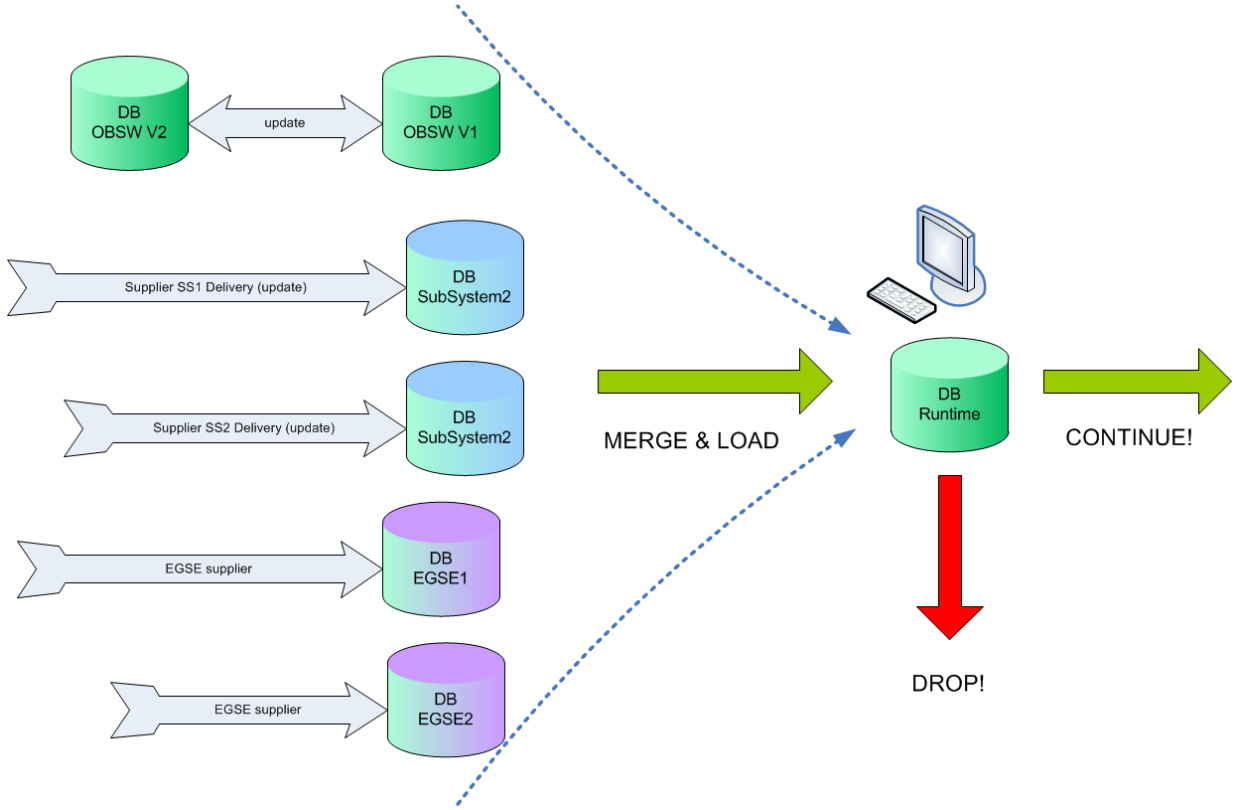
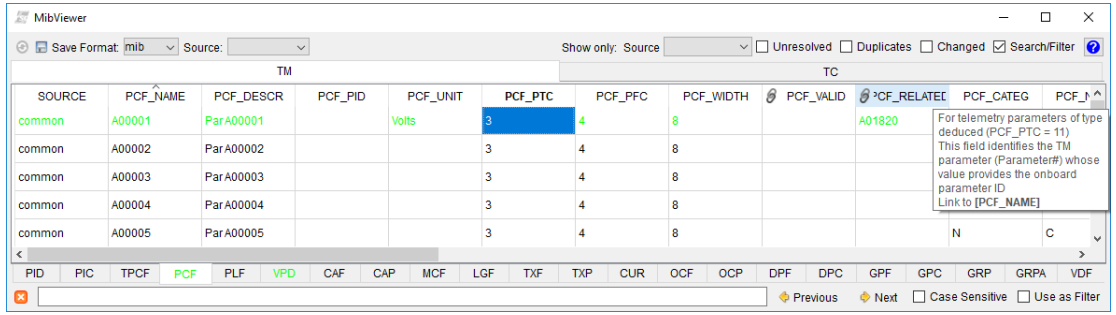
Merging TMTC Databases



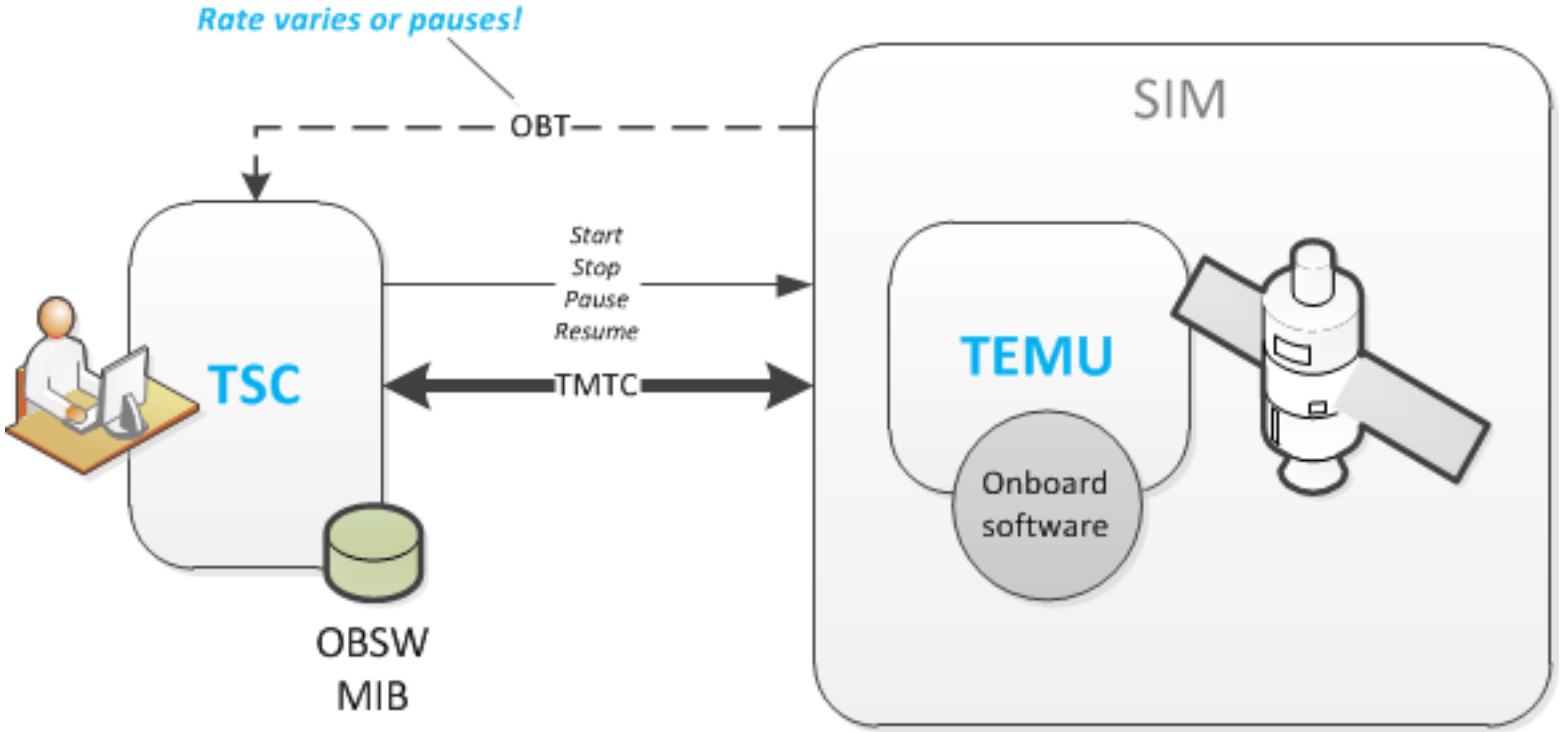


MIB databases may come from different suppliers, arriving at different times, changing

- Need to merge from different sources (Platform, Payloads, Instruments, EGSE)
- Drop / load / continue (no need to restart)
- Online access / directly view MIB contents with documentation, search, filter & patch features

Clean separation of data from different sources

SVF Mode

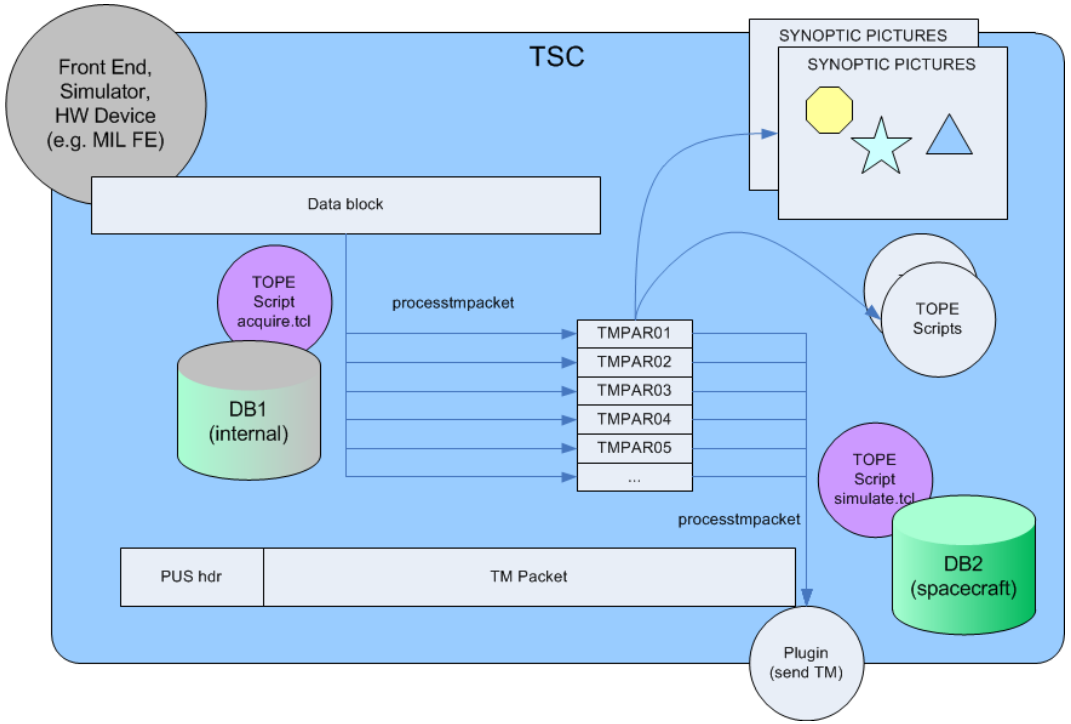


SVF (Software Validation Facility) often includes a simulator and onboard computer emulator

- The simulation time frame may vary (pause, resume, speed up, slow down)
- In SVF mode, TC verification timers and TOPE sequence timers vary with the simulated time

For Terma emulator (TEMU), see also: https://temu.terma.com

TM Simulation



TM packets can be simulated according to the MIB definition (inverts TM processing). This allows (for example)

- Acquire data from a device or other source (e.g., orbit propagator) then publish it in the layout of the spacecraft (platform simulation)
- Generate SCOE telemetry (act as SCOE controller)
- Test development and debugging (exercise displays, exercise TOPE scripts)
- Implement light spacecraft or subsystem simulations

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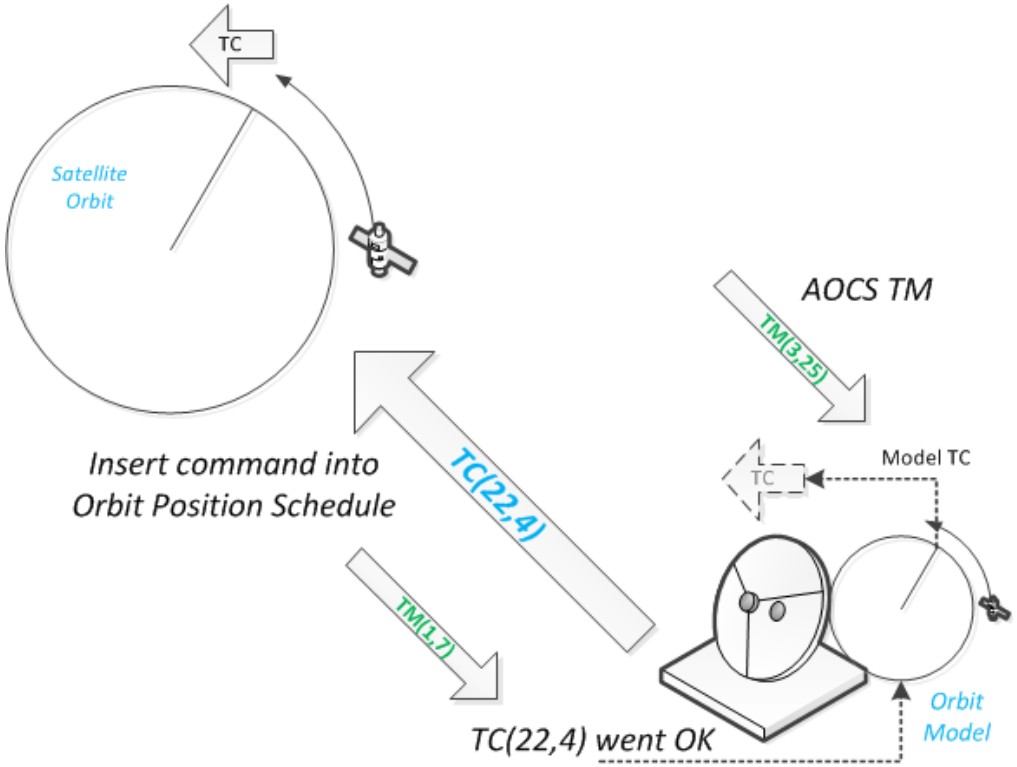
Advanced TC Modelling & Cyclic TC



To model a TC, activate verification for a TC, even if we did not send it

- Cyclic TC: completes when repeat count property reaches zero.
- Verification (re)opens according to model (e.g. based on orbit telemetry) in TOPE
- Optionally models verification of nested TC (commands within commands)

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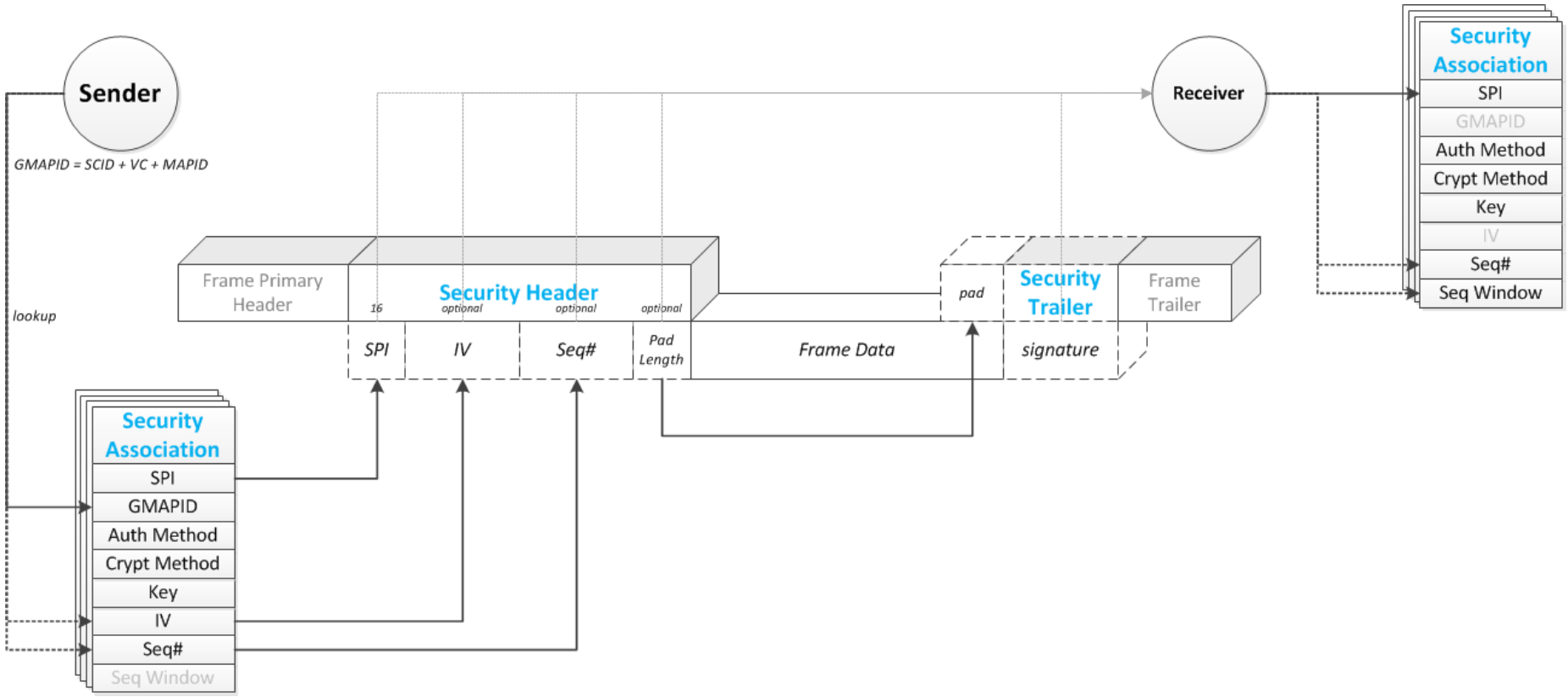
Authentication & Encryption



The system supports (built-in, in software)

- CCSDS 355-0-B1 & 355-1-B1 extended procedures, authentication (CMAC, HMAC, GMAC, CBC-MAC) encryption (ECB, GCM, CCM)
- ESA PSS-04-151 hard knapsack authentication & “Sentinel1” enhancement using CMAC
- Key management UI’s.
- Adaptable to separate deployment (e.g. towards NIST FIPS-140 compliance)

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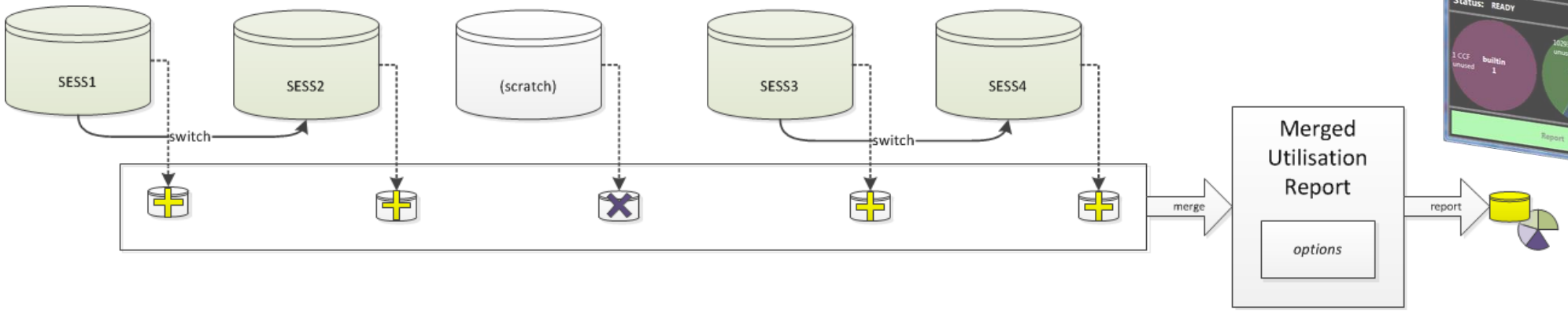
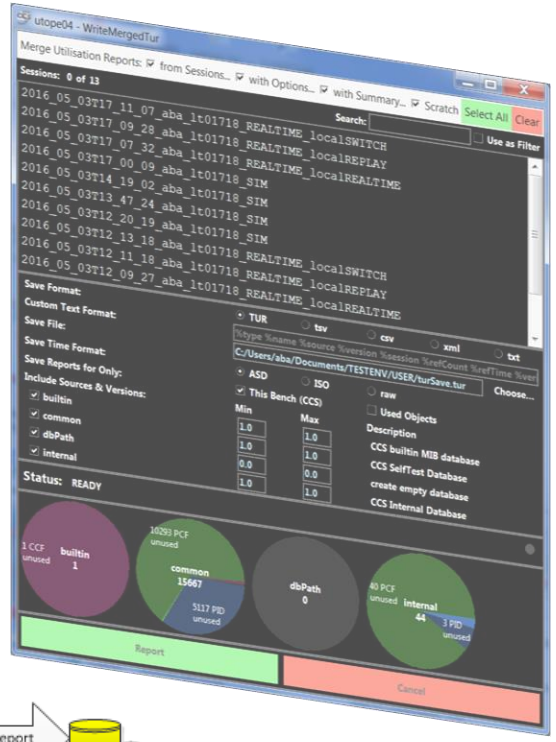
Test Coverage Reporting

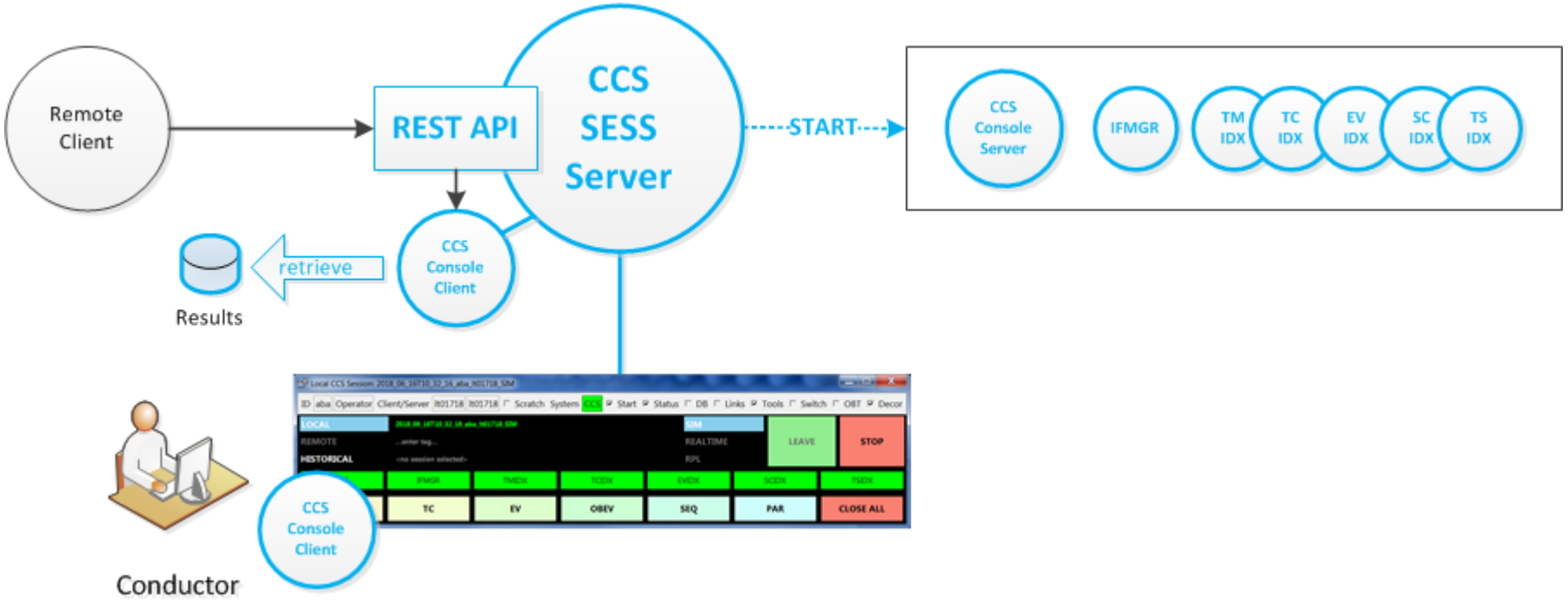




End customers (e.g. ESA) sometimes ask for test evidence, e.g. usage of MIB objects

- Tests may involve a large number of sessions and large number of objects
- Some sessions are formally significant, while many sessions are “scratch”
- Due to potential data size, selecting and merging has to be very efficient
- Different missions and companies have different report formats

CCS Web Services



- Allows remote clients to use a REST API to:
  - Start/stop sessions (& run automated tests)
  - Retrieve TM parameters

- Allows increased automation (e.g. automated production line, automated operations)

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ADVANCED APPLICATIONS FOR AIT

Instrument EGSE & Science Data Processing

Typical configuration:

- High-end workstation (e.g. 8 cores) running TSC
- Electrical front-end equipment (e.g. Power + MIL 1553 + SpaceWire)
- MATLAB used for graphing and visualization (mission customized)
- TSC controls front ends & processes instrument TM & TC using instrument MIB

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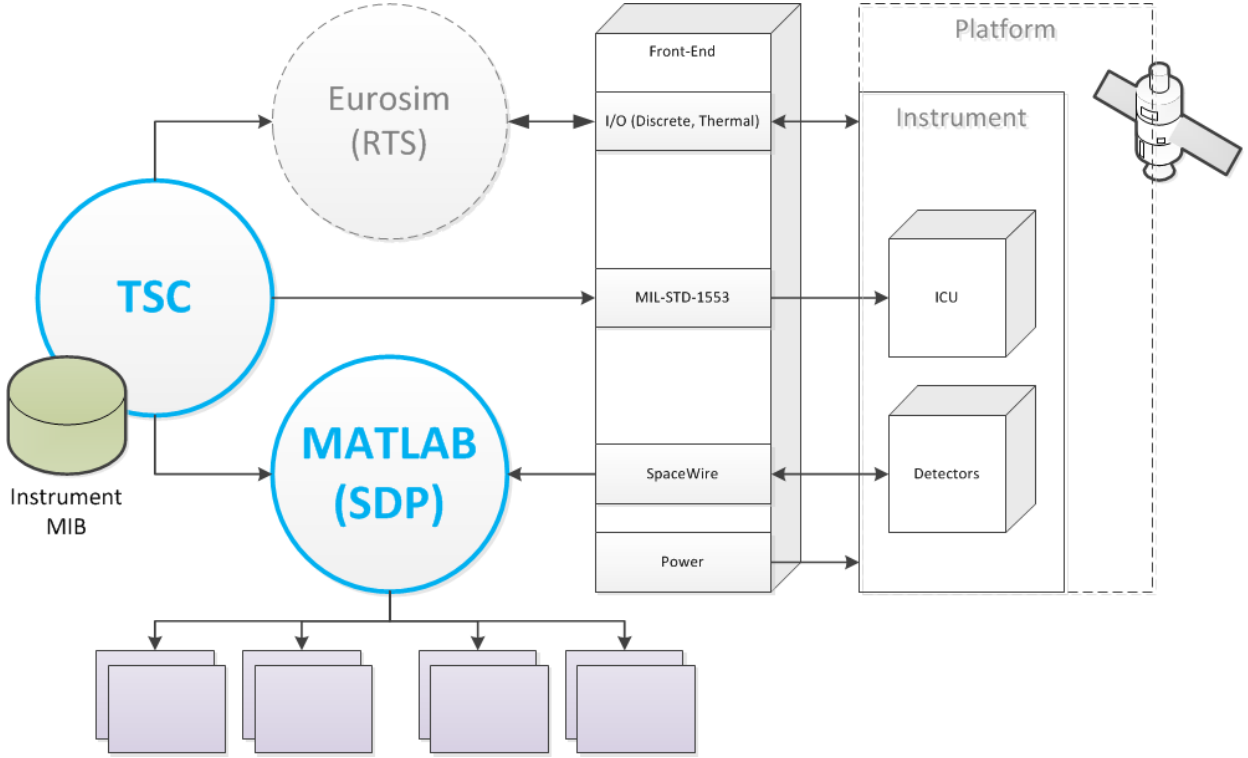
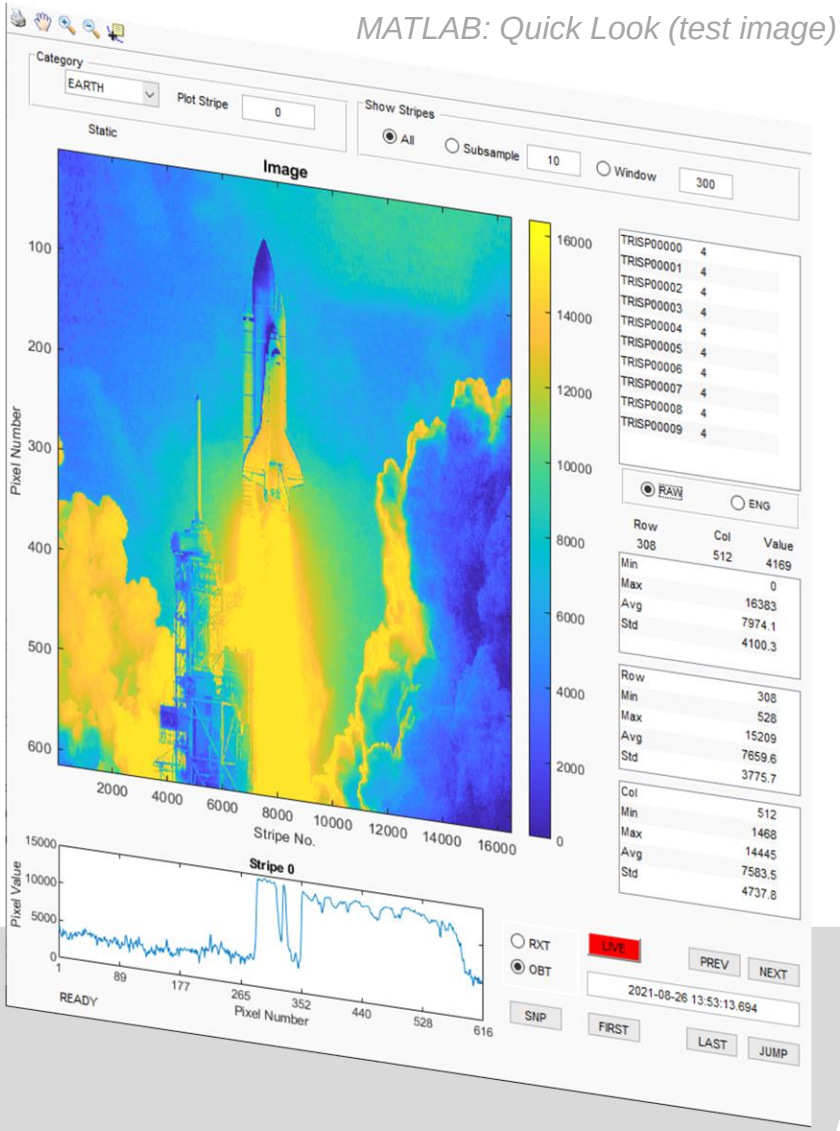
Instrument EGSE & MATLAB Example



MATLAB: Quick Look (test image)



- Instrument Control Unit with MIL-1553 front-end for Housekeeping TM and TC
- Science data: typical up to 4 x SpaceWire interfaces, 8 x CCD source
- TOPE interfacing to Simulator (in this case, EuroSim)

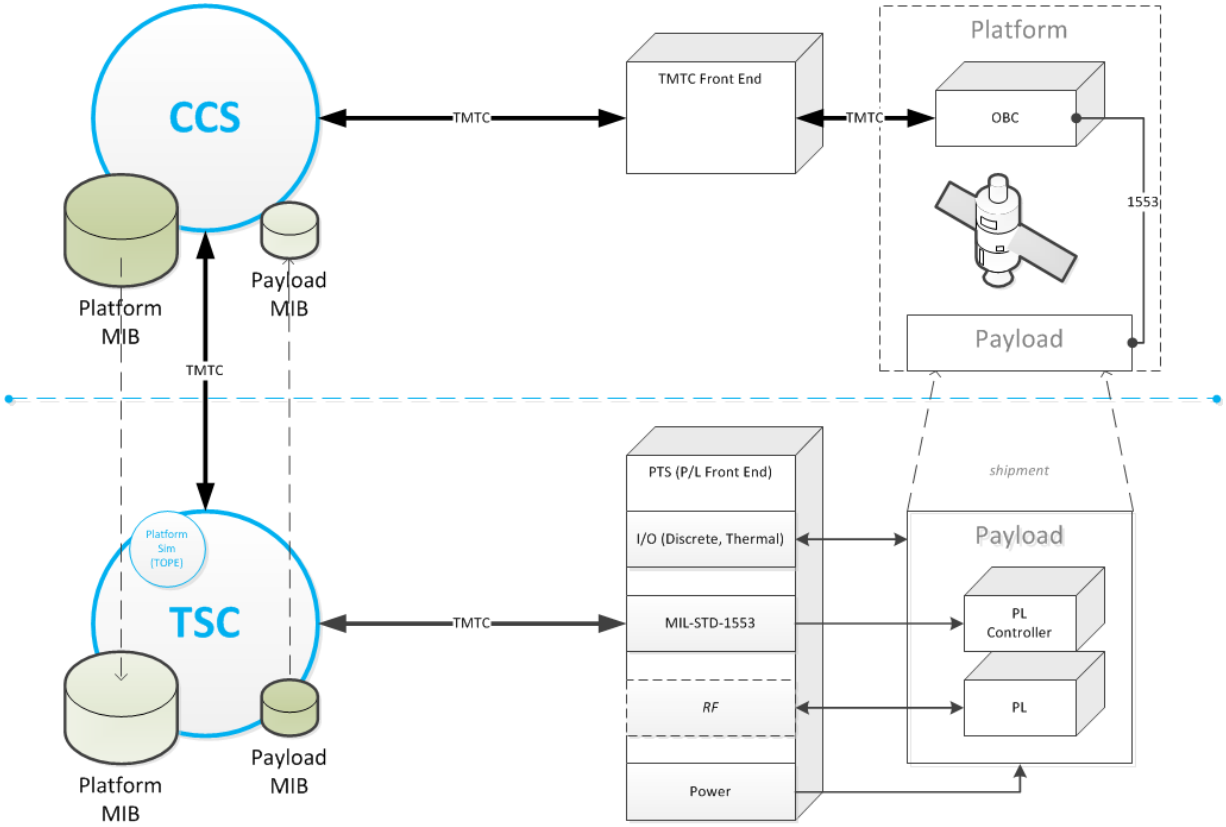
Payload EGSE & Platform Simulation

Typical configuration:

Mission P/L and platform suppliers are different companies

P/L and platform each tested with the other absent, until payload delivered

Payload & Platform EGSE Example



Platform uses CCS, payload uses TSC, configured with same EGSE protocol (e.g. EDEN, C&C)

- TM simulation capabilities allow platform to be simulated & platform TC to be sent to P/L
- Allows coordination of MIB contents & inter-site testing prior to shipment

User Roles & Deployment

Issues considered:

User roles & privileges (protection & security)

Speed of deployment (quick, secure, configuration of different users)

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User Roles & Deployment Detail

Login relies on operating system (password validation, file permissions)

Access to application features is based on role, e.g. “Operator”, “Guest”

- Capabilities define access to a feature e.g. “canSendTelecommand”
- Capabilities are configured on/off by role.
- Unless prevented, users can change role instantly

Default set of “typical” roles & capabilities is usually configured at installation

- New roles can be defined, or custom capabilities of an existing role
- Specific capability “canSwitchMode”; defines whether user can change to another role
- Role changes, if allowed, are applied instantly

“Global Settings” feature:

- Defines all roles and capabilities for all users, differentiated by group ID
- Speeds up deployment & configuration for big systems
- Improves security (prevents users from configuring their own capabilities)

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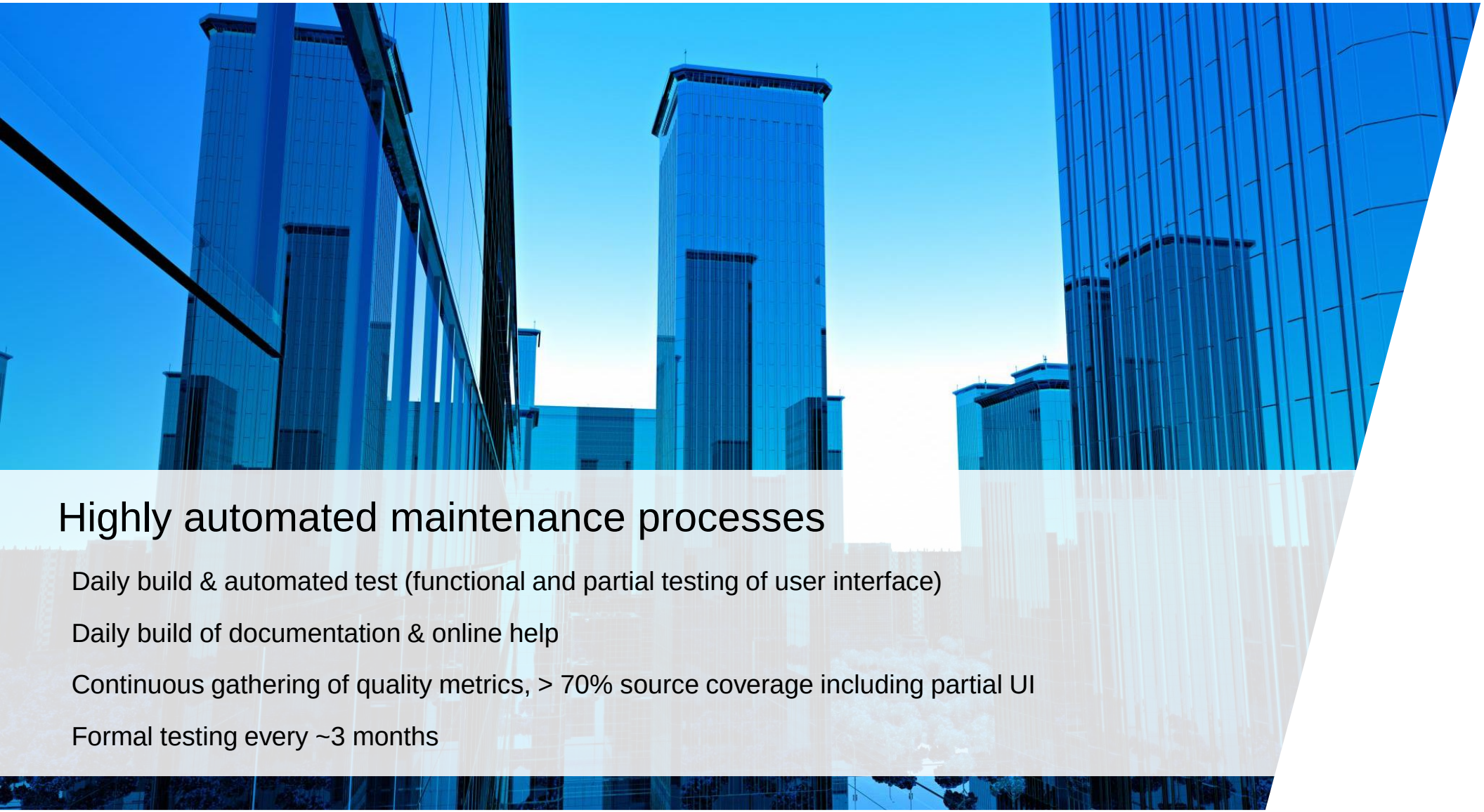
Quality & Testing



Highly automated maintenance processes

Daily build & automated test (functional and partial testing of user interface)

Daily build of documentation & online help

Continuous gathering of quality metrics, > 70% source coverage including partial UI

Formal testing every ~3 months

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Legal, Licensing & Purchasing

System is Terma IPR

Uses small number of 3rd-party tools:

- Included in installation:
  - Qt 5 (commercial license)
  - Tcl 8.6 (BSD license)
  - NATS (Apache 2.0 license)
  - SQLITE (Public domain) used by TSC
- Not included in installation, needed for CCS
  - RDBMS (MySQL, Maria DB, PostgreSQL, AWS Aurora or other compatible)

License is perpetual:

- Warranty (e-mail support) 1 year included in license
- Subsequent years: 20% of license cost
- Support WIKI available to customers with active licenses

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