The Transportable Integrated Geodetic Observatory (TIGO)

(Operational Requirements)

Abstract

The Bundesamt für Kartographie und Geodäsie (BKG) will provide a major contribution to the improvement and maintenance of the global reference frames

- ICRF (International Celestial Reference Frame),
- ITRF (International Terrestrial Reference Frame)

provided by the International Earth Rotation Service (IERS) with the operation of TIGO (Transportable Integrated Geodetic Observatory).
TIGO is designed as a transportable geodetic observatory which consists of all relevant geodetic space techniques for a fundamental station. It is a German contribution to the Global Geodetic Observing System (GGOS).

This Paper describes the objectives of TIGO for the global reference frame, the TIGO-system and its components and requirements, benefits and requests to the host country, procedure of application.

1. Objectives of TIGO

The global reference frames ICRF (International Celestial Reference Frame) and ITRF (International Terrestrial Reference Frame) are the basis for all geodetic reference frames applied in continental and national areas. Today the geodetic space techniques are highly efficient and cost-effective for scientific and practical applications. The geodetic space techniques such as

- VLBI (Very Long Baseline Interferometry),
- SLR (Satellite Laser Ranging),
- Microwave based observations to navigation systems GPS (Global Positioning System), GLONASS and in future Galileo are realizing the global reference frame ITRF through an international network of geodetic stations - the International Space Geodetic Network (ISGN) - consisting of
- radio telescopes for VLBI,
- laser ranging systems for SLR/LLR,
- permanent GNSS-stations.

The global distribution of the geodetic stations is unbalanced (IERS, Annual and Technical Reports). A dense network of stations exist in North-America, Europe and parts of Asia (Japan), whereas gaps in the network are obviously on the Southern Hemisphere.
For the minimization of systematic effects and errors the ideal distribution for the IGSN would be a homogeneous network. It is obvious, that the realization is an international task, regardless to political borders. International and bilateral cooperations are required, which finally result in the benefit for all by the existence of a highly precise global reference frame.
The international coordination of the contributions is performed through the international services which are under the umbrella of the International Association of Geodesy (IAG), namely the

- IVS (International VLBI Service),

- ILRS (International Laser Ranging Service),
- IGS (International GNSS Service).

The combination of the products is guaranteed through the

- IERS (International Earth Rotation Service).

The Bundesamt für Kartographie und Geodäsie (BKG) has developed the Transportable Integrated Geodetic Observatory (TIGO) for the support of the realization and maintenance of the ITRF and ICRF. TIGO is currently located in Concepcion, Chile. Due to the transportability the contribution to the ITRF can be optimized in dependence of the location and of the duration of operation at one site. In order to fill gaps in the global reference frame network the area for operation is preferably on the southern hemisphere.

2. Transportable Integrated Geodetic Observatory (TIGO)

TIGO is a rigorous development of a fundamental station in order to provide observations for the

1. realisation of the geodetic global reference system,
2. maintenance of the global reference frame,
3. monitoring of the Earth orientation parameters,
4. monitoring of the crustal movements.

All relevant geodetic space techniques are realized with TIGO:

- Very Long Baseline Interferometry (VLBI), Satellite Laser Ranging (SLR),
- Global Positioning System (GPS) and comparable navigation systems.
- For the conduction of observations with space techniques and for the correct interpretation of observational data additional local measurements are indispensable, like
- measurements concerning the local time and frequency keeping providing the local timescale and reference frequencies,
- gravity measurements for monitoring the Earth tides,
- seismic measurements for monitoring earthquakes,
- meteorological measurements for monitoring the troposphere,
- local survey measurements for monitoring the site stability.

TIGO has its own electric power generators in case there is no or instable power supply at the remote site.

Transportability of the observatory is achieved by building the whole observatory into six 40-feet-standard containers, which are certified for sea transportation. It is assumed, that according to its specifications TIGO can be shipped to any remote location outside arctic or antarctic environments in the world. After installation of TIGO some of the containers serve as the operation rooms. Figure 3 gives an overview about TIGO.

It is planned, that TIGO will occupy a remote site for a period of more than two years before it will be moved to another site. The un-/loading procedure of the containers from/to a truck is possible simply with muscle power (no crane needed).

2.1. VLBI

Very Long Baseline Interferometry (VLBI) is a geometric technique which measures the time difference between the arrival at at least two Earth based radio telescopes of a radio wavefront emitted by a distant quasar. Because the time difference measurements are precise to a few picoseconds, VLBI determines the relative positions of the cooperating radio telescopes to a few millimeter and the positions of the quasars to a few milliarcseconds. The very distant quasars provide an inertial reference frame which is two orders of magnitude more accurate than the well-known fundamental catalog of fix stars FK5. Since the radio telescopes are fixed on the rotating Earth, VLBI tracks instantaneous the orientation of the Earth in an inertial reference frame - an indispensable information for any kind of satellite orbit determinations.

VLBI observations as a microwave technique can be performed under all meteorological conditions.

The elements of a geodetic VLBI station consists in general of

- a radio telescope with a cryogenic dual band S/X-band receiver, ® a data acquisition terminal for bandwidth frequency synthesis,
- a hydrogen maser as very precise frequency standard to which all local oscillators in a VLBI-system must be phase-locked,
- a data formatting and recording device for the temporary storage of digitised quasar noise.

Usually the VLBI-data consists of digitised noise from the quasar and is recorded with a time stamp on magnetic tapes at the stations. After the completion of the observations within an experiment the magnetic tapes must be shipped from all co-observing stations to a VLBI-correlator. After the arrival of these tapes the interferometer is setup at the correlator. The correlation process plays back the recorded data from all the station simultaneously and the processor searches for the maximum of the cross-correlation-function. The correlator output are the fringe phase and the fringe amplitude from which the delay and delay rate of the wavefront can be derived. The delay is the primary observable in geodetic VLBI and shown in figure 4.

TIGO VLBI-Module

The VLBI-module contains a 6 meter offset-radio telescope, which is the largest instrument of TIGO. Its mass is about 23 tons. The radio telescope can be transported in two containers. The design allows that two persons are able to setup the whole VLBI-module within a week without any crane (fig. 5 - 10).

The technical parameters of the TIGO radio telescope are summarised in table 1.

The data acquisition terminal is a Mark IV compatible so called VLBA4 terminal. It is controlled by the NASA PC Field System running on PC under the Linux operating system. The data are recorded on one-inch magnetic thin tapes at the VLBA4 recorder.

Usually the VLBI operation is scheduled within the International VLBI Service (IVS). The main program is the continuous observation of the rotation of Earth (CORE) in which a VLBI station observes in different global VLBI networks one to three times a week for 24 hours. For a 24 hours experiment with about 300 source observations the qualified operator needs about 2 hours of checkingout the equipment prior the experiment and about 1 hour for administrative tasks after the experiment. The presence of an operator during the 24 hour of observations to control the overall performance of the automated execution of the observations is a necessity.

The TIGO VLBI-module is equipped with measuring tools like spectrum analyser, frequency and time counters, power meter, digital oscilloscopes, signal generator, chart recorder and the necessary mechanical tools. For the maintenance of the cryogenic cooling system a vacuum pump and helium bottles are available. Many of the most important spare parts are also available in order to minimise the downtime clue to technical problems at the remote site.

The operation and the maintenance of the VLBI equipment requires expertise in high frequency technologies, analog and digital electronics, cryogenic cooling, vacuum technology, atom physics for the atomic clocks, mechanics, celestial mechanics, computer interfaces, Linux operating system, programming.

The geodetic VLBI experiments are a non-profit international effort organised by the International VLBI Service (IVS).

2.2. SLR

Satellite Laser Ranging (SLR) is a pulse-echo measuring technique, which uses lasers to measure ranges from ground stations to satellite borne retro-reflectors. Because the events of sending and receiving a pulse can be registered within a few picoseconds, SLR determines the position of the ground station and of the satellite within a few millimeter. SLR is a dynamical measuring technique since the target at the satellite is moving in an orbit through the gravitational field of Earth. Hence the satellite is a sensor for the lower frequency parts of Earth's gravitational field, which allows the determination of the center of mass of Earth. Since the very compact and passive SLR-satellites have a very stable orbit, SLR plays an indispensable role in the definition of the origin and the scale of a global geocentric reference frame.

SLR is due to the use of optical wavelengths dependent on clear sky and the absence of clouds during the satellite passes.

The elements of a SLR-station are shown in figure 12 and consists in general of

- an optical telescope for high-energy laser pulses,
- a laser pulse generator a time measurement system with event timers,
- a control computer for the computation of orbit predictions, controlling the telescope and processing the returns.

Predicted orbits are available for each satellite in order to compute the pointing angles for the telescope tracking. Operators adjust three offsets: time bias, along-track and across-track in order to find return signals. The registered returns are processed at the SLR-station after the observation has been made. Several hundreds of returns are summarised to a few so called normal points. The tracking report after a successful observation contains information about the offsets to the predicted orbit elements and the normal-points.

TIGO SLR-Module

The TIGO SLR-module consists of one container in which the telescope and the necessary equipment can be stored during the transportation. At the remote site the cart-mounted 50cm-optical-telescope can be positioned precisely above the reference marker. The components of the laser pulse generation and detectors are indoors in a clean-room environment. The laser pulses are guided through a connecting tunnel between telescope and container. The SLR-system is specified to track

from low orbit satellites at about 300 km altitude up to geostationary satellites at about 36000 km altitude. If the telescope is moved out of the container, the gained space is transformed into the operators room from which the laser ranging is performed.
The Gallilean type laser telescope includes two mirrors which are inclinated with respect to the telescope main axis. Therefore the folded beam enables a very compact design of the telescope and the use of the full aperture of 50 cm avoiding any front lens mirror.

The azimuth bearing is realized as an air bearing over a polished granite block. Therefore the mass of the cart with telescope is about 1700 kg.
The laser system provides two colours based on Titan-Sapphire crystal which is tuned to wavelengths of 847 nm and 423.5 nm. The Titan-Sapphire laser amplifiers are pumped with Nd:YAG laser. The SLR-module contains for the use at a remote location without prohibited.
zone for aircrafts a Doppler radar for aircraft detection. The technical parameters are summarised in table 2.

Tab. 2: Technical parameters of the TIGO SLR-module.

Parameter	TIGO-SLR
owner and operating agency year of construction optical telescope system aperture optical efficiency max. field of view pointing accuracy	BKG 1996 folded Gallilean, transmit/receive 50 cm 75% 4 arcmin < 2 arcsec
wavelengths pulse duration pulse frequency pulse energy divergence	847 nm, 423.5 nm 80 ps 10 Hz 30 mJ each wavelength 0.4 mrad

The TIGO-SLR-module is equipped with measuring tools like 400 MHz analog oscilloscope, digital oscilloscope, time and frequency counter, wavelength meter and laser power meter. The most important spare parts are available at the SLR-module in order to minimise telescope downtime due to technical problems at the remote site.
For aircraft security a Doppler-radar is added to the SLR-module. If any aircraft will be detected to be close to the laser beam, the laser will be shutoff in order to avoid blinding of the pilot.
The operation and maintenance of the SLR equipment requires expertise in laser systems and its safety regulations, analog and digital electronics, optics, celestial mechanics, statistics, radar technique, computer interfaces, Linux operating system, programming.
SLR measurements are carried out on a non-profit international base which are coordinated by the International Laser Ranging Service (ILRS).

2.3. Techniques concentrated in the TIGO Basic-Module

The basic-module of TIGO comprises devices for

- microwave techniques such as G PS-receivers,
- time and frequency keeping,
- gravity measurements,
- seismic measurements,
- meteorological measurements,

- the local survey of TIGO,
- data administration and communication,
- local energy generation,
- maintenance of the TIGO devices, and o a social room described in the following subsections.

2.3.1. GNSS

The Global Positioning System (GPS) consists of 24 satellites in 6 orbital planes with a height of 20000 km. The satellites transmit on two carrier frequencies coded informations. A ground based GPS receiver can determine its position, if at least signals of four GPS transmitters are received. Nowadays geodetic networks are formed with permanent GPS tracking stations, from which positions can be derived on the millimeter level.

GPS as microwave technique provides weather independent observations. A GPS permanent station consists of

- an omnidirectional antenna,
- a receiver with monitor and control capabilities,
- a data storage and communication unit.

TIGO includes four permanent GPS Ashtech Z12 receivers with choke ring antennas. One receiver will be collocated at the TIGO platform next to the VLBI- and SLR-telescopes. Three receivers will be used in the region around the TIGO platform in order to monitor the site stability.

The data of all four GPS receivers will be administrated and made available through the central data server of the Basic module of TIGO.

The operation and maintenance of the GPS-array of TIGO requires expertise in GPS technology, computer interfaces and data communications.

GPS measurements are made on a non-profit base which are coordinated by the International GPS Service (IGS).

2.3.2. Time and Frequency

Geodetic space techniques require a high precise frequency and time keeping. For an observatory the locally generated time scale is essential. Two kinds of atomic clocks are necessary:

- hydrogen masers, with a short term stability of about 10-15 Allan-variance for VLBI, SLR and GPS,
- cesium standards, with a long term stability of about 10^{-13} Allan-variance as reference.

An additional special GPS-time receiver is used for time transfer and for the synchronisation to GPS reference clocks.

TIGO contains two hydrogen masers, two cesium standards and two GPS time receivers. These oscillators are referenced to one cesium standard as master clock of TIGO by using 1 pps signals which are derived from phase locked clock modules. A control computer registers each 3 hours the clock offsets. Occasionally the clock rates must be readjusted. The offset of TIGO master clock versus GPS can be reported to the BIPM BIPM in Paris since the requested hardware for the international timing service is available.

The TIGO time and frequency standards are powered by batteries, which are charged by solar energy and station power.

The operation and maintenance of the time and frequency laboratory requires expertise in atom physics, high frequency technology, electronics, computer interfaces.

2.3.3. Gravity

Temporal variations of the gravity force are measured by a gravimeter. The gravimeter signal provides informations about the response of the elastic Earth e.g. due to tidal forces, ocean and atmospheric loading.

The measurement principle of a so called superconducting gravimeter consists of a hollow sphere suspended by a magnetic field which is produced by currents in superconducting coils. Owing to the missing resistance the currents in the coils are nearly constant, therefore this gravimeter has a long-term stability. Forces acting by accelerations on the probing body are compensated by regulating the current in an additional coil, which serves as the signal.

Due to the small instrumental drift and the high resolution of the signal (relative sensitivity of 10-11) it is possible to cover the spectral range of the acceleration variation from seismic eigenmodes over the Earth main tides up to the variation in the centrifugal force due to the Chandler period of about 435 days in the polar motion.

A superconducting gravimeter is part of TIGO. It requires a silent pillar indoors. The cryogenic cooling is achieved with a helium compressor. The compressor is water cooled and needs a water supply at the site.

The operation and maintenance of the superconducting gravimeter requires expertise in cryogenic cooling, gravity, electronics, computer interfaces, UNIX operating system.

2.3.4. Seismicity

The geodetic space techniques provide site position and velocity by long term records. For the correct modelling of the site velocity it is necessary to monitor events like earthquakes. A broad spectrum seismometer records earthquake events.

Seismometers are usually operated in regional or global networks. The data of a seismometer network registers the earthquake events at different arrival times. The computation of the wave propagation enables the determination of the epicenter.

The TIGO broad spectrum seismometer is a Giiralp Systems CMG-3T instrument. It consists of 3 orthogonal sensors with a sensor mass of 0.180 kg each. The positions of the masses are monitored by capacitive sensor. The processed signal outputs are position and velocity of the sensor masses in vertical, north-south and east-west direction.

The TIGO seismometer is designed to be located at a silent place near the TIGO platform. It has a solar panel for its local energy supply and is controlled remotely via 200 m long optical fibres from the basic-module of TIGO. The time reference is taken from an own GPS-time receiver at the seismometer site.

The operation and maintenance of the broad spectrum seismometer requires expertise in seismometers, analog/digital electronics, computer interfaces, solar power, GPS, Linux operating system.

2.3.5. Meteorology

The limiting factor in the accuracy of space geodetic techniques is the atmosphere. For the correction due to refraction meteorological measurements are indispensable.

TIGO contains a complete meteorological station with sensors for dry temperature, relative humidity, air pressure, wind direction, wind velocity and a rain counter. In addition a water vapour radiometer (WVR) is used for the determination of the zenith wet path delay.

The weather samples are recorded each 15 minutes by a computer and are made available via database to the users. Actual weather data samples for the refraction correction during trackings are also available.

The WVR measures continously profiles at different directions. One profiling takes about 15 minutes and results in one zenith wet path delay value.

The operation and maintenance of the meteorological sensors requires expertise in meteorology, meteorological sensors, electronics, high frequency technology, computer interfaces, programming.

2.3.6. Local Survey

The local survey at a fundamental station with various geodetic space techniques ties the reference points of the telescopes and phase centers into a local geodetic network. The space vectors between the reference points enable the tie among the geodetic space techniques. Since geodetic space techniques are accurate to a few millimeter in a global scale, the local survey should aim to be one magnitude better in accuracy. Therefore only geodetic precision instruments can be used for this task.

A periodically repetition of the local network measurement verifies the stability of the TIGO platform with respect to its local surroundings. For this purpose special monuments must be available at the TIGO platform. The regional stability is monitored with the TIGO-GPS-axray (see above).

The local survey equipment of TIGO consists of a tachymeter Geotronics Bergstrand, a digital levelling instrument Zeiss DiNill and accessories. A processing software called GeoGenius is also included.

The local survey requires expertise in geodesy, statistics, coordinate determinations, data communication.

2.3.7. Data Administration and Communications

Observation schedules and logfiles as well as acquired data needs to be temporarily stored or archived, administrated and send to or received from the user communities. These are tasks for the central computer server which is the interface to the wide area network.

A Linux based PC-server with a RAID fix-disk mass storage system, a backup system and a CD- writer is available. The TIGO-LAN is based on optical fibres between the server and hubs inside the containers. The backup systems are part of the server. The server is protected with an uninterruptable power supply. All TIGO printers are connected to the LAN. The database of TIGO is based on PostgreSQL. For communications TIGO owns a telephone system based on ISDN technology and an Inmarsat telephone (for emergency calls). Several spare parts for the LAN and tools are available. The operation and maintenance of the central computer server requires expertise in computer hardware and interfaces, WAN/LAN technology, in the system administration of a LAN server based on the operating system Linux, data base systems, backup systems, programming and several standard software packages, telephone systems.

2.3.8. Energy

Any activity requires energy. Moving telescopes, air-conditioning, running computers and atomic clocks require stable and continuous power supply. If the remote site cannot provide electricity according to north European standards, TIGO can be powered autonomously by its Diesel generators. Six 25 kW generators are available and can be used according to the necessary load. The maximum load is expected to be about 120kW, that means that always one generator can be maintained without interruption of the operation.

Atomic clocks and some computers should always be powered. Therefore an additional solar energy supply, consisting of 4 kW solar panels mounted on top of one of the containers and the necessary batteries, realizes the uninterruptable power supply. The batteries can be charged by the generators as well.

The operation and maintenance of the energy module of TIGO requires expertise in electricity, power generators, diesel engines, photovoltaic and batteries.

2.3.9. Maintenance

Technical devices function properly if they are maintained regularly. Therefore workshops are indispensable in which repairs and maintenance procedures can be performed.

TIGO is equipped with a 2 workspaces electronic laboratory and a 1 workspace fine mechanical workshop. Necessary tools and materials for TIGO are present.

For several tasks heavy goods needs to be lifted. TIGO owns a Toyota forklift of the 2 tons class, which can be operated by authorised persons only.

2.3.10. Social Room

TIGO is operated by humans. The need of humans are different from those of machines. TIGO has one convention room for 14 persons in order to organise working shifts at staff meetings.

The convention room contains also the first-aid equipment.

A small kitchen offers for operators during night shifts the possibility to warm up meals. TIGO has a fresh water tank for about 500 liters and another one as sewage collector. TIGO is designed to treat the environment friendly.

TIGO does *not* provide beds for accommodation nor toilets. It is anticipated that a basic hygienic infrastructure can be provided by the hosting country.

3. Cooperation of BKG with a Host Country

TIGO will provide a significant contribution to the global reference frame by the submission of data of geodetic space techniques complemented by local measurements. The operation of TIGO is only feasible in a close cooperation between the BKG and the host country on a bilateral agreement. Regulations have to be settled for the

- location of the operation of TIGO,

- period of the operation of TIGO,
- provision of the infrastructure,
- support by additional staff,
- sharing costs of the operation,
- education and training of staff,
- data handling,
- scientific benefits,
- publication of results.

Although the operation of TIGO is a non-commercial business, some advantages for the hosting country should be advertised. The exploitation of the advantages should be done by partner institutes in the hosting country.

3.1. TIGO as fundamental reference point for national survey

TIGO will be scheduled to observe within international measuring campaigns on a longterm and continuous basis. Therefore TIGO will provide (after one year of observation) an excellent determined reference point within the global reference frame of the ITRF.
With the appearance of geodetic space techniques the definition of national geodetic networks has to be reconsidered generally.

Tab. 3: Differences in the definition of national geodetic networks in the past and today.

	History	Present
Direction	azimuth to fix stars, ±1 arcsec	direction to quasars, ±0.001 arcsec
Origin	defined at one main reference point, triangulation introduced errors of several meters	defined by exhaustion of velocities over many reference points, millimeter accuracy level
Scale	baseline enlarging network	provided by VLBI, LLR, GPS
Position	static, only coordinates	kinematic, coordinates and velocities
Physical model	Newtonian spacetime	relativistic spacetime
Earth model	solid Earth	elastic Earth

The accuracy in the geodetic networks have been improved during the last three decades of at least two orders of magnitude due to the geodetic space techniques and due to the continously improved models in the analysis procedures.
Today the historical measuring principle "from the large to the small" is still applicable as in previous triangulation networks. But its meaning today is: *from the inertial system defined by quasars to any point in a country.* This principle is realized by the International Celestial Reference Frame (ICRF) based on the quasars and by the fundamental stations within the ITRF as backbone plus single technique ITRF-sites. Any point in a country is determined by the most efficient network-densifying-technique GPS which will be tied into the frame of the ITRF. Any national network computation can make use of the most accurate ITRF point positions and velocities if some ITRF sites are included in the domestic surveys.
The fundamental stations mark a high precise reference point in a global as well as in a national reference system.

TIGO is by its concept and its equipment a fundamental station created for this task.

3.2. Scientific exploitation of TIGO

TIGO will occupy a new site on the globe where little or no knowledge about its geodynamical behaviour might exist. The setup of TIGO has the capacity to bring up new information about the selected site with respect to global geodynamic changes.

3.2.1. Geodynamics

Given the fact that TIGO has provided data at one location for a period of at least one year, it will be possible to determine the crustal motion of this site during the observation period. After a reoccupation of the former TIGO site it will be possible to continue the measurements. This will result in a more significant longer time span.
The regional tectonics will be monitored with three GPS receivers of the TIGO-GPS-array.
Additional devices like gravimeter and seismometer deliver also information regarding the geodynamic effects and might verify the globally measured velocities.

3.2.2. Earth Rotation

TIGO provides VLBI observations which are dedicated to the precise determination of Earth orientation parameters in an inertial frame. The high resolution Earth rotation parameters contain signals regarding the global changes. As an example: The El Niño Southern Oscillation (ENSO) effect can be identified and predicted by the study of Earth orientation parameters. If e.g. TIGO is located near a region which is effected by ENSO, the local effects can be measured and compared with the global signal in the Earth orientation parameters.

3.2.3. Earth Tides

For the modelling of Earth tides, of atmospheric and ocean loadings the TIGO gravimeter will provide data from a new place. The local changes of gravitation might also contain hints of subduction or uplift in the long term.

3.2.4. Atmosphere

The atmosphere is a limiting factor of the accuracy of geodetic space techniques. Humidity is a strong source of attenuation of microwaves. With the TIGO-GPS-array and the TIGO-water vapour radiometer it will be possible to derive independently the water content in the atmosphere and to determine the zenith-wet-path-delay model for the atmospheric layers above the TIGO site.
The two frequency VLBI-observations in S-/X-band and the GPS-array in L-band allow the determination of the electron content of the ionosphere.
The two-colour laser system allows the determination of the dispersion due to the atmosphere.

3.2.5. Local Survey

Since TIGO requires a very precise local control network for deformation analysis at the TIGO site. The reference pillars offer the possibility to be used as a test range for electro-optical distance measuring devices or for GPS-antenna calibrations.

3.2.6. Timekeeping

TIGO has the capability to serve the hosting country as a backup system for the national reference time emission. Studies between the national time keeping authority and TIGO regarding its synchronisation and syntonisation are possible.

The generation of a local time scale is provided by TIGO. The TIGO clock ensemble however, should be synchronised to UTC via time transfer experiments. TIGO offers with its space geodetic techniques also the capabilities for various time transfer experiments.

4. Considerations for the Operation of TIGO

TIGO is supposed to operate abroad at a remote site in a hosting country. TIGO serves primarily the task to improve and maintain global reference systems. This task is an international common non-profit effort. BKG as the owner of TIGO has the interest to find partner agencies, institutes, administrations in the hosting countries (called 'partner'), which share the interest in this task. The decision on the first abroad location for TIGO has to consider various aspects:

1. **Global Reference System.**
   The BKG has the task to maintain the reference systems for domestic purposes. Since there is a general understanding that global phenomena have an effect on the domestic issues, BKG has to contribute to the international efforts for the maintenance and improvement of the still insufficient realization of a global reference system. TIGO is a German contribution to this international task and to the Global Geodetic Observing System (GGOS).
   The geometrical distribution of the reference points in the global reference frame is inhomogeneous. Therefore undesired systematics occur, e.g. in the orbit modelling of SLR-satellites. TIGO can be brought to remote sites to improve the situation in the most efficient manner.

2. **Geology.**
   Reference points in a global reference system are intended to be used in the long term. Therefore a solid underground like bedrock would enable a good foundation. Further the absence of recently active fault zones is mandatory. If regional movements are present, they must be observed and modelled.

3. **Climate.**
   TIGO was specified for extra antarctic and extra arctic environments. TIGO has air-conditioning systems for the rooms of operation and with electronic devices.
   TIGO-SLR requires clear sky for observations. The probability of clouds or fog (day and night) should be less equal than 50%.
   The radio telescope of TIGO can be operated up to 80 km/h wind speed.

4. **Physical environment.**

   TIGO-VLBI requires an area where there is no radio frequency interference in S- and X-band. Mobile telephones, television and radio broadcast stations are using often S-band for data communication and can make with their high-frequency pollution VLBI observations impossible.

   The seismometer and the gravimeter require a tectonically quiet location. Streets with frequently passing heavy trucks should be in a larger distance. Dust is undesired due to the optical instrument.

5. **Social environment.**

   Education systems and levels are expected to be different from those in Germany. TIGO offers the opportunity for the interchange of experiences and knowledge. However *the success of TIGO will be measured in the quantity and quality of produced data.* Therefore the ability to work dedicated for this goal is anticipated from each cooperating partner.

   Mentality and language differences are enriching for the variety of societies, but they might cause problems in the understanding of a common sense. TIGO concentrates a lot of high-technology instruments and tools which demand a common sense about a proper treatment. It is important, that staff working at TIGO have a true interest in the tasks and the observatory.

   TIGO needs suitable operators which should be provided by the partner, which will be trained initially by BKG staff at the TIGO-site.

6. **Political environment.**

   Bilateral agreements on the cooperation are advantageous or should be made. TIGO has a civil and no military use.

4.1. Desired Contributions from the Partner

BKG intends to run TIGO at a remote site for periods of about 3 years. As BKG is providing a complete observatory and staff of 3 experts, the infrastructure and additional manpower should be provided by the partner(s).

4.1.1. Property

The property should be provided by the partner and coincide with the following specifications:

- **Size.**

  TIGO requests space for six 40-feet-containers (12.20 m). It must be possible to setup the containers in the way shown in figure 3 - otherwise the manufactured cables are not suitable. In front of the containers must be a minimum space of additional 18.00 m, so that the truck can navigate during the (un-)loading action of the containers (fig. 5). Therefore the solid area for trucks with a mass of 40 tons must be about 50 x 50 m^2. The ground can consists of rolled ballast.

  Additional space is needed for the gravimeter, seismometer, parking area and other infrastructure like toilets.

  A property of the size of about 70 x 70 m^2 is suitable.

- **Location.**

1. **Climate.** Clear sky probability larger than 50%. Wind above 80 km/h should occur not often than five times a year and should not exceed 120 km/h.
2. **Geology.** No recently active fault zone. Bedrock desirable.
3. **Surroundings.** Observations down to 5° elevation should be possible with no obstacle around the horizon.
4. **Radio frequency interference.** TIGO-VLBI needs a location which is unpolluted by S/X-band transmitters.
5. **Natural hazards.** Areas with a large risk due to floodings, tsunamis, flashes, etc. are excluded.
6. **Health.** Areas with known risks for TIGO-staff due to infections with diseases, radioactivity, dioxine, etc. are excluded.

- **Site.**

  TIGO needs special concrete foundations for the VLBI-radio-telescope and the SLR-module. Geodetic observation pillar must be built at the platform for the local control network and in the surroundings for the regional control network.

  To avoid problems with electrical installations a central ground for all TIGO devices is requested. A protected foundation for the gravimeter and the seismometer is necessary. A toilet is needed at the site.

- **Infrastructure.**
  1. **Streets.** TIGO platform must be reachable by trucks with a mass of 40 tons and with trailers carrying standard 40-fcet-containers.
  2. **Accessibility.** TIGO platform should be accessible from populated areas within one hour car drive. Since VLBI requests a quick magnetic tape transportation an airport within about a two hours car drive distance is of advantage. Public transportation connection might be necessary for TIGO staff.
  3. **Electrical Power.** TIGO is operated with 400 V three-phase current resp. 230 V one- phase current, both at 50 Hz. The maximum load will be about 120 kW.
  4. **Water.** TIGO requests water for the cooling of the helium compressor for the gravimeter and for consumption by staff.
  5. If a sewage interface cannot be provided an environmental friendly solution for it should be realized.
  6. **Communications.** TIGO needs to send and receive data on the Internet 24 h, seven days a week. Telephone and fax accessibility is also of importance.

- **Protection.**

  The TIGO platform must be protected with a fence against curious persons and animals. A gate should be large enough, that trucks can enter the property.

  Platform, gate and fence should be for security reasons illuminatable at night.

- **Disposal.**

  The TIGO platform should be reachable by the refuse disposal service. Facilities at the site for the temporary storage of hazardous or contaminated waste (e.g. oil) from other garbage must be provided.

4.1.2. Staff

BKG will contribute 2 experts and requests support from the partner for

operation, the execution of observations 24 hours seven days a week;

maintenance, repairs and regular maintenance of TIGO devices;

services, administration, guarding the site, gardening, cleaning.

TIGO is a complex system and it is expected that the individual staff cooperates flexible in a best effort way according to the situations at the site. A rough estimate of the number of staff and their desired qualifications are given in table 4. Some duties can be done by university students also.

Tab. 4: Staff necessary at TIGO in the hosting country. First three staff are expatriated from BKG, eleven staff are expected from the partner. This is a rough estimate. University students can be trained for some duties as

Type	Number	Background	needed since	from
supervising expert	1	geodetic engineering	always	BKG
	1	electrical engineering	always	BKG
operator	2	high frequency	TIGO setup	partner
	2	laser specialists	TIGO setup	partner
	2	geodetic/software engineering	TIGO setup	partner
	1	mechanician	TIGO setup	partner
technician	1	electro technician	platform building	partner
	1	surveying	platform building	partner
	1	infrastructure	platform building	partner
	1	mechanician	platform setup	partner