Automatic Low-Cost GPS Monitoring System using WLAN Communication

FIG Working Week 2012

TS 03F - **Deformation Monitoring I**

Commission 6

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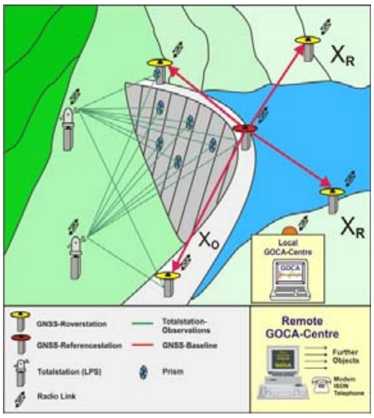
Introduction & Motivation

Monitoring is one of the main tasks in Engineering Geodesy.

Tendence of the monitoring:

- discontinuously → continuously
- post-processing → automatic and in near real time



Source: http://www.goca.info/index_e.html

Beside the tachymeter, only the GNSS receivers can measure the 3D positions automatically and continously.

Problem: investment cost will be high, if a big object should be monitored.

>20,000€, geodetic GPS receiver, dual-frequency

Accuracy? →

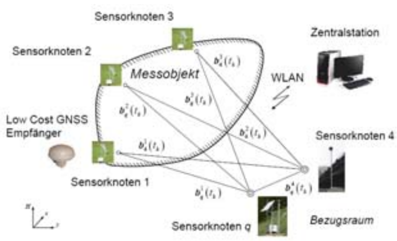
<100 €, low –cost GPS receiver, single-frequency

Introduction & Motivation

In a multipath and shadowing free environment the accuracy level of low-cost GPS receiver is **better than 2 cm** at an observation time of 20 minutes. This accuracy almost meets the requirements of geodetic applications.

Volker Schwieger, Andreas Gläser: *Possibilities of Low Cost GPS Technology for Precise Geodetic Applications*. FIG Working Week 2005 in Cairo, Egypt

Using low-cost receiver is economical solution for geodetic applications



Otto Heunecke: *Zur Nutzung von Low Cost GNSS Sensorik in der Ingenieurgeodäsie – Möglichkeiten und Grenzen.* Kalrsruhe, Februar 2011

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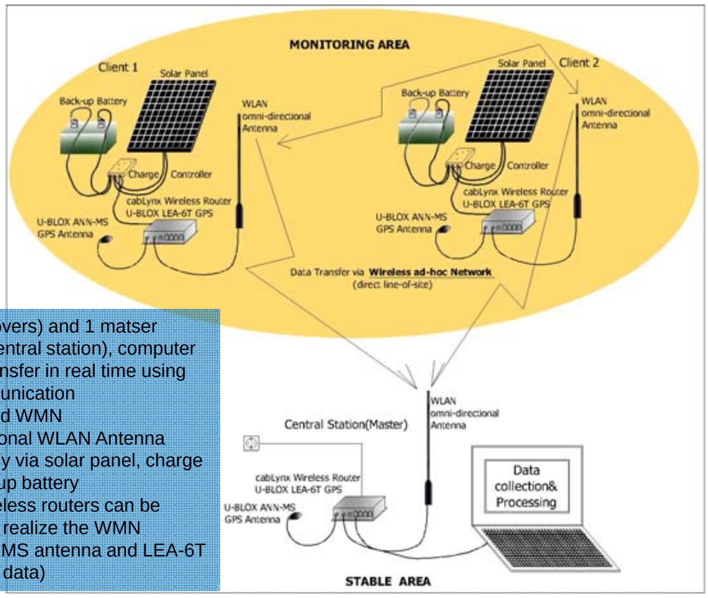
System Architecture



2 clients (rovers) and 1 matser (reference, central station), computer
raw data transfer in real time using WLAN communication
Self-orgnized WMN
omni-directional WLAN Antenna
power supply via solar panel, charge cotroll, back-up battery
cablynx wireless routers can be configured to realize the WMN
u-blox ANN-MS antenna and LEA-6T receiver (raw data)

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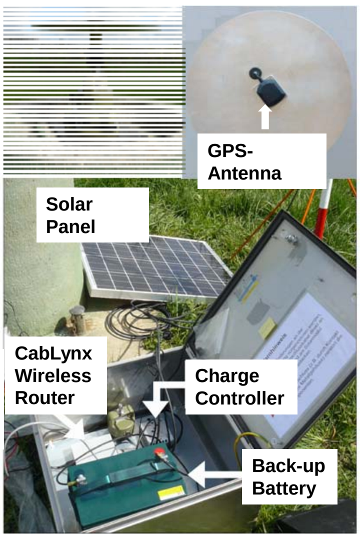
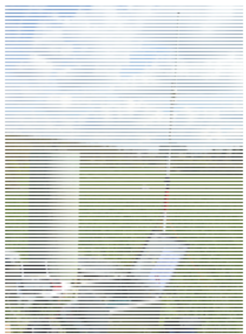
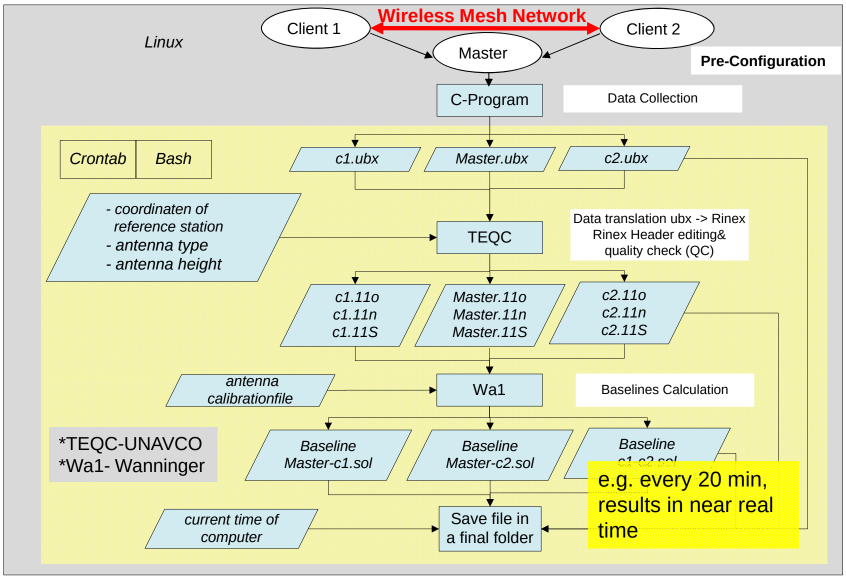
System Components

Omni-directional WLAN-Antenna





Automatic Data Collection and Processing



First Experiences &Test Results – WLAN Range

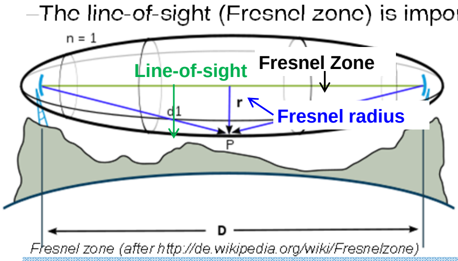
Information about WLAN range is important for measurement planning, number of receivers: as small as possible but no less than necessary

Several distances (about 1.1 km, 1.2km, 1.6km, 2.1km, 2.6km) were tested in an area (close to Stuttgart airport)

The WLAN range can be longer than 2.6 km with line-of-sight (enough for normal monitoring tasks)

Data missing at some points because of obstructions

The line-of-sight (Fresnel zone) is important for WLAN communication



Fresnel zone (after http://de.wikipedia.org/wiki/Fresnelzone)

The radius of the first Fresnel zone:

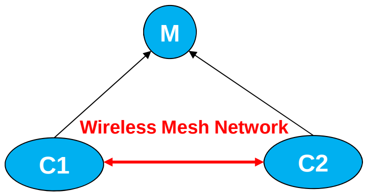
$$r = 17.31 \cdot \sqrt{n \frac{d_1 \cdot d_2}{f \cdot D}}$$

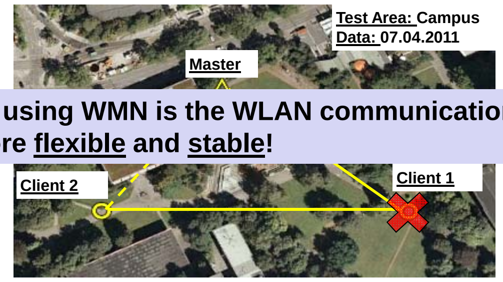
At least about 60% of the Fresnel zone should be kept free from the obstructions

Source: http//www.vias.org

Consideration about Fresnel zone is important for the measuremnet plan. The WLAN antennas should be set up as high as posssible, in order to have less obstructions within the Fresnel zone.

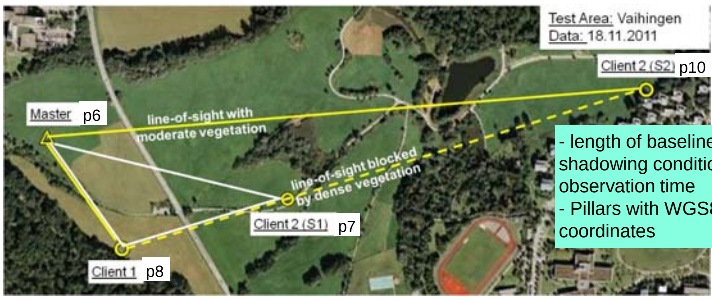
First Experiences & Results – Test of WMN





By using WMN is the WLAN communication more flexible and stable!

First Test Results – Test Scenarios (Accuracy)



- length of baseline, shadowing condition, observation time
- Pillars with WGS84 coordinates

Session No.	From		To		Distance	Start	Stop
	Router	Pillar No.	Router	Pillar No.	[m]		
1	Master	6	Client 1	8	254.913		
	Master	6	Client 2	7	468.638		
	Client 1	8	Client 2	7	322.313		
2	Master	6	Client 1	8	254.913		
	Master	6	Client 2	10	1128.809		
	Client 1	8	Client 2	10	1024.573		

-Same baseline in both sessions: Master – Clien1
- Client 2(p7->p10)
-Shadowing free: p6&7
-Shadowing: p8&p10

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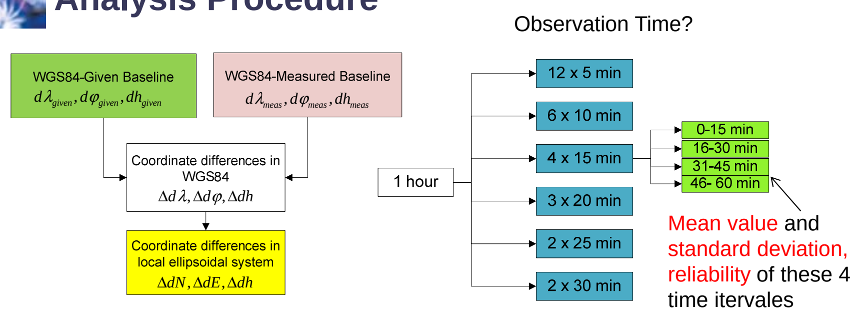
Analysis Procedure



•The standard deviations calculated by Wa1 software are very good, they are all <1 mm for the solutions with fixed ambiguities (too optimistic) ->The results of the different time intervals are compared among each other.

Mean Value: reproducibility (absolute) accuracy
Standard Deviation: repeatability (relative) accuracy
Reliability: percentage of the solutions of total results.

•The results of 5 minutes intervals are not accurate and unreliable. Only about 50% of the measurements have solutions with fixed ambiguities. So, only the results of 10 to 30 minutes time intervals will be presented.

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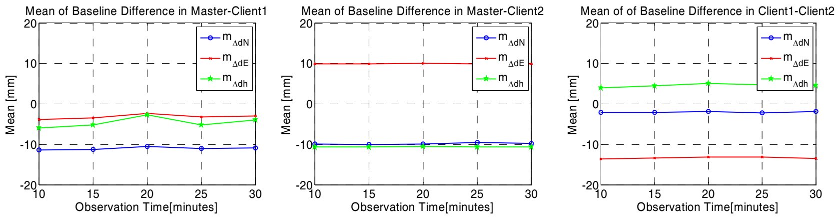
Accuracy Analysis Session 1

Time Interval	Session1	Mean [mm]			Standard Deviation [mm]			Reliability
		mΔdN	mΔdE	mΔdh	sΔdN	sΔdE	sΔdh	[%]
10min	Master(p6)&Client1(p8)	***-11.4***	-3.8	-5.9	4.8	2.6	6.9	100.00%
15min		***-11.2***	***-3.5***	-5.2	4.7	0.9	6.2	100.00%
20min		-10.5	***-2.4***	-2.7	2.5	0.4	1.3	66.67%
25min		-11.0	-3.2	-5.2	4.8	1.0	5.0	100.00%
30min		-10.9	***-3.0***	-4.0	4.3	0.3	3.5	100.00%
10min	Master(p6)&Client2(p7)	***-9.9***	***9.9***	-10.6	2.1	0.8	4.7	100.00%
15min		***-10.0***	***9.9***	-10.7	2.2	0.7	4.9	100.00%
20min		***-9.9***	***10.0***	-10.5	2.2	0.4	3.7	100.00%
25min		***-9.6***	***9.8***	-10.6	1.5	0.2	6.0	100.00%
30min		***-9.8***	***9.9***	-10.6	0.2	0.4	3.7	100.00%
10min	Client1(p8)&Client2(p7)	2.1	***13.6***	-4.0	5.1	2.4	9.8	100.00%
15min		2.1	***13.4***	-4.4	4.8	1.6	8.9	100.00%
20min		1.8	***13.1***	-5.0	3.0	0.7	4.5	100.00%
25min		2.2	***13.1***	-4.8	5.3	0.9	9.0	100.00%
30min		1.9	***13.5***	-4.6	3.7	1.6	8.1	100.00%

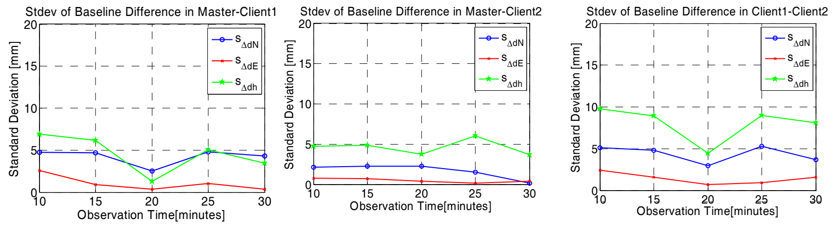
- reproducibility (<1.2cm) and repeatability (<1cm) accuracy is not improved with longer observation time.
- quite reliable, only one 20min time interval with float solution.
- systematic errors?
  statistical significance t-tests $t = \frac{m_{\Delta dN}}{s_{\Delta dN}} / \frac{m_{\Delta dE}}{s_{\Delta dE}} / \frac{m_{\Delta dh}}{s_{\Delta dh}} \text{ vs. } t_{f,95\%}$

Accuracy Analysis Session 1

Mean	M-C1	M-C2	C1-C2



Stdev	M-C1	M-C2	C1-C2



Accuracy Analysis Session 2

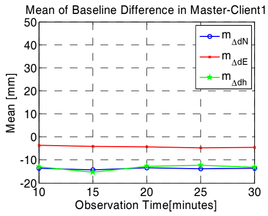
Time Interval	Session2	Mean [mm]			Standard Deviation [mm]			Reliability [%]
		mΔdN	mΔdE	mΔdh	sΔdN	sΔdE	sΔdh	
10min	Master(p6)&Client1(p8)	-13.7	-3.7	-13.0	2.5	1.6	10.5	83.33%
15min		-14.3	-4.1	-15.4	2.1	2.4	7.0	75.00%
20min		-13.3	-4.3	-12.7	1.9	1.5	8.6	100.00%
25min		-13.7	-4.8	-12.3	1.3	2.0	9.1	100.00%
30min		-13.7	-4.5	-13.3	1.0	2.4	9.5	100.00%
10min	Master(p6)&Client2(p10)	-17.5	28.9	-9.8	2.4	1.2	7.9	83.33%
15min		-16.7	29.3	-7.8	0.3	0.8	5.6	75.00%
20min		-18.0	28.8	-10.4	2.7	1.0	7.7	100.00%
25min		-17.6	28.8	-9.6	2.0	1.7	9.6	100.00%
30min		-17.7	28.9	-10.0	2.4	1.2	8.4	100.00%
10min	Client1(p8)&Client2(p10)	-5.3	33.6	-0.5	2.1	2.2	7.7	50.00%
15min		-4.6	32.4	-0.9	2.8	1.8	3.3	50.00%
20min		-5.7	33.5	-2.4	0.9	1.5	3.6	66.67%
25min		-6.3	32.4	-1.7	0.3	3.1	1.2	100.00%
30min		-6.5	32.3	-0.8	0.1	2.4	1.6	100.00%

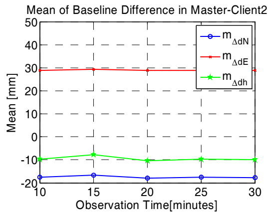
- reproducibility (<3.5cm, worse than 1. session because of shadowing environment) and repeatability (<1cm) accuracy is not improved with longer observation time.
- Unreliable results for 10 and 15 min solutions (because of shadowing environment)!
- systematic errors-> statistical significance t-tests
- Any change for the same baseline in both sesssions: M-C1?

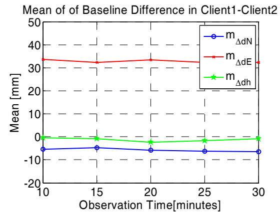
$$d_{\Delta dN} = m_{\Delta dN1} - m_{\Delta dN2}, t = \frac{d_{\Delta dN}}{s_{d_{\Delta dN}}} /\ldots \text{ vs. } t_{f_d,95\%}$$ ->No!

Accuracy Analysis Session 2

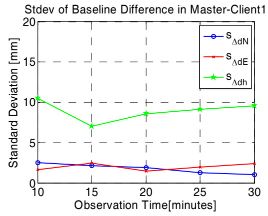
Mean	M-C1	M-C2	C1-C2

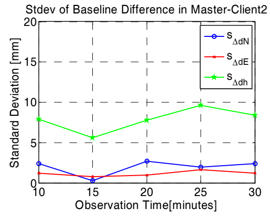


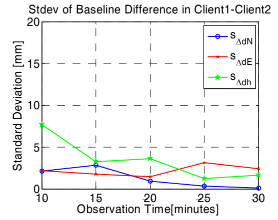




Stdev	M-C1	M-C2	C1-C2







Accuracy Analysis

- The reproducibility (absolute) accuracy and repeatability (relative) accuracy do not improve with longer observation time (starting from 10 minutes). But in shadowing environment, the reliability will be better with longer observation time.
- The repeatability accuracy< 1cm.
- The reproducibility accuracy< 3.5 cm, contain systematic errors, possible reasons for the systematic errors

unsuitable antenna calibration file (with/without ground plate)

the low-cost antennas are different, individual calibration is necessary
shadowing environment, multipath effect!

More measurements are necessary!!

Conclusions

- An automatic low-cost GPS monitoring system using WLAN communication is developed and introduced, the first experiences and test results
- The WLAN Range can be longer than 2.6 km with line-of-sight
- The Fresnel zone should be taken into the consideration of measurement plan
- WMN improve the flexibility and stability of the WLAN communication
- The WLAN communication, data collection and processing is automatic
- The optimal observation time depends on the environment (10 min for shadowing free, 20min even 30min for shadowing environment)
- The repeatability accuracy< 1cm
- The reproducibility accuracy< 3.5 cm

Outlook

- Individual antenna calibration with ground plate
- Test with different GPS antenna with “low cost” C
- Remote control of system via Internet considering
- Filter algorithms …

In the near future, we will have 4 different GNSS (GPS, Glonass, Compass, Galileo) which include more than 100 satellites, availability and reliability will grow, the economic potential of low-cost GNSS system for monitoring tasks should not be underestimated!

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