Synergies Between Satellite Navigation and Location Services of Terrestrial Mobile Communication

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OVERVIEW

- Targets of communication and satellite navigation
- Positioning using mobile communication
- Implementation with GSM and UMTS
- Error budget and simulations
- Rough estimate on required infrastructure
- Conclusions

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MOBILE COM vs. SATNAV 1

Phenomena	Communication	Navigation
Basic function of the system	Error free transmission of large amount of data	Global 3D positioning and timing with high accuracy and integrity
Quality parameter	BER = 10^{-3} to 10^{-6}	2drms = 0.01m to 100m
Connection	Up- and Down-Link	Down-Link
Coverage	Terrestrial	Terrestrial, airspace, maritime, space
Number of transmitters	Large: > 100.000 global	Small: 20 – 30 global
Requirements on Rx – Tx configuration	Contact to one and only one Tx	Simultaneous contact to as many Tx as possible (at least 4)
User data rate	High: > 2 Mb/s for UMTS	Low: 50 – 200 b/s

MOBILE COM vs. SATNAV 2

Phenomena	Communication	Navigation
System planning	Maximize data rate and number of users	good geometry for positioning (DOP)
Propagation path	Non-LoS not critical, even desired	LoS essential
Multipath, number of reflectors	Not critical	Critical
Power control	Necessary	Not necessary
Required synchronization	0.25 Bit or Chip	< 0.01 Chip

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POSITIONING USING MOBILE COMMUNICATION 1

Network-based positioning	Positioning done using signals and hardware only of the wireless system
Handset-based positioning	Positioning done using an independent positioning system (GNSS etc.)
Hybrid positioning	Positioning done using several independent positioning systems (GNSS, LORAN-C etc.)
Self positioning	All measurements and calculations related to positioning performed inside MS
Remote positioning	All measurements and calculations related to positioning performed inside network

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POSITIONING USING MOBILE COMMUNICATION 2

Handset-based positioning

- Each sensor operates independently: no integration
  - Such handys already available
- „Wireless Assisted GNSS (GPS)“
  - First implementations and experiences, also indoors
- Integration of handset and GNSS functions
  - First investigations

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GEOMETRICAL PRINCIPLES

- **Time of Arrival (ToA)**

  MS at intersection of circles

  Synchronisation of BSs and MS required

- **Time Diff. of Arrival (TDoA)**

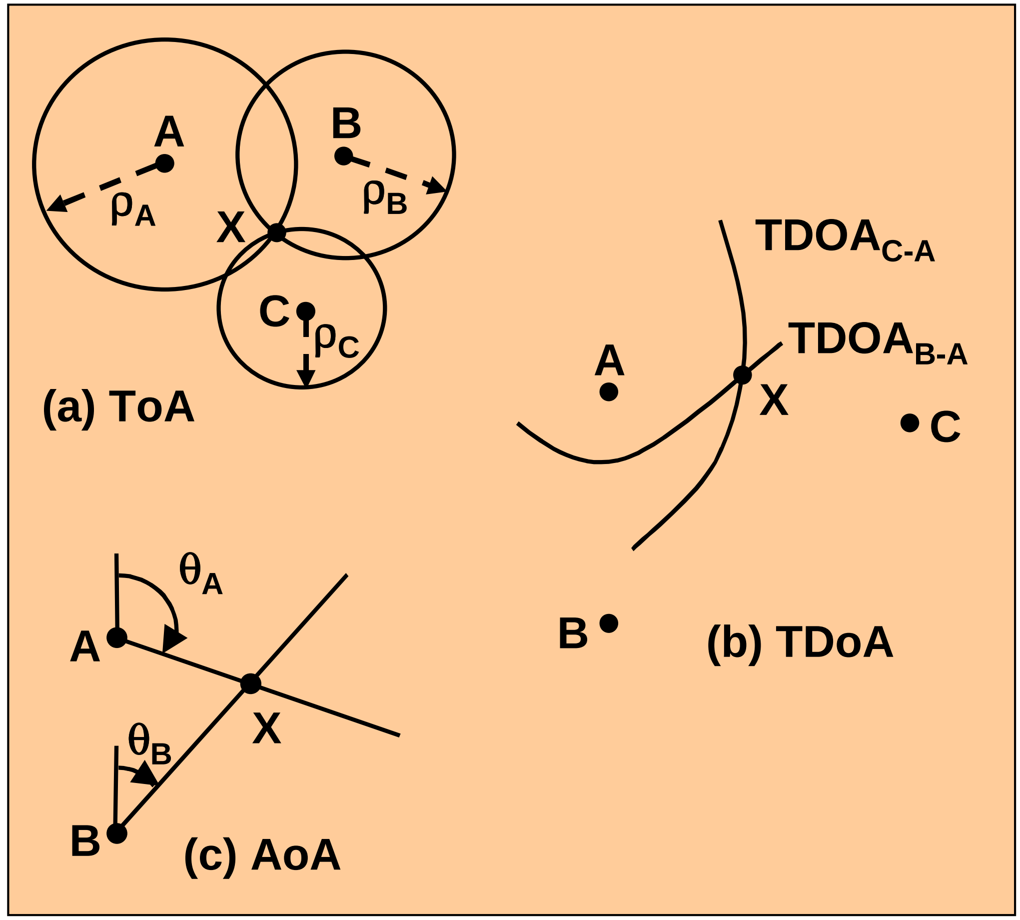
  MS at intersection of hyperbolas

  Synchronisation of BSs required

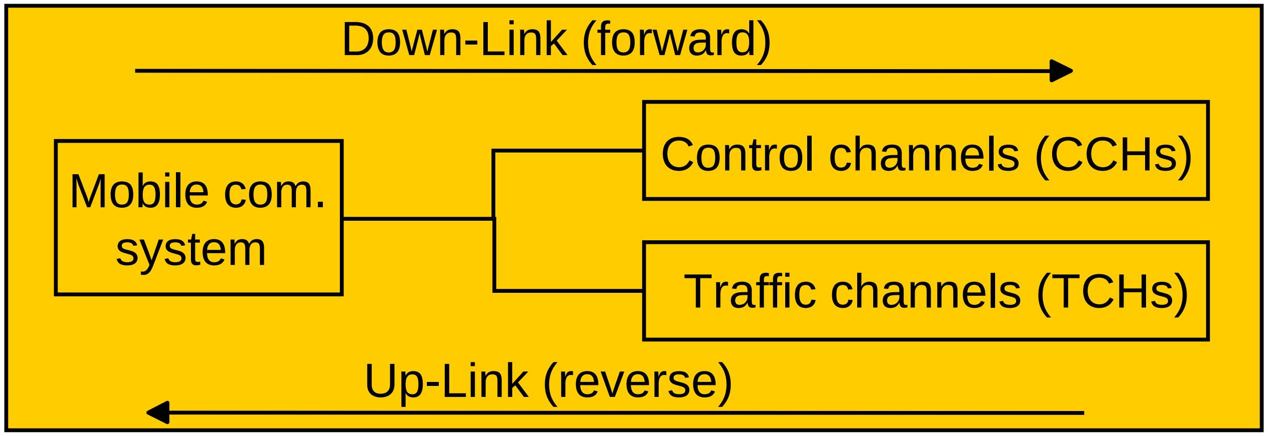
- **Angle of Arrival (AoA)**

  MS at intersection of directed lines

  No synchronisation required



WHICH CHANNEL IS SUITABLE FOR LCS ?



Parameter	**Up-Link Control channel**	**Down-Link Control channel**
Self positioning	**No**	**Yes**
Number of users	**Limited**	**Unlimited**
MAI potential	**High**	**Low**
Variation of C/N_o due to power control	**Large**	**Moderate**
Hand-over	**Easy**	**Difficult**
Modification of signal	**No**	**Yes (IPDL)**
Capacity impact	**Negligible**	**Present**
Handset modification	**No**	**Yes**

IMPLEMENTATION IN GSM AND UMTS

	GSM900	UMTS
Multiple Access	FDMA: 200 kHz bandwidth per carrier frequency TDMA: 8 channels per carrier freq.	FDMA: 5 MHz bandwidth per carrier freq. CDMA TDMA: 16 channels
Frequencies	DL: 890-915 MHz UL: 935-960 MHz	DL: 2110-2170 MHz UL: 1920-1980 MHz
Bit rate	271 kbit/s	2 Mchips/s

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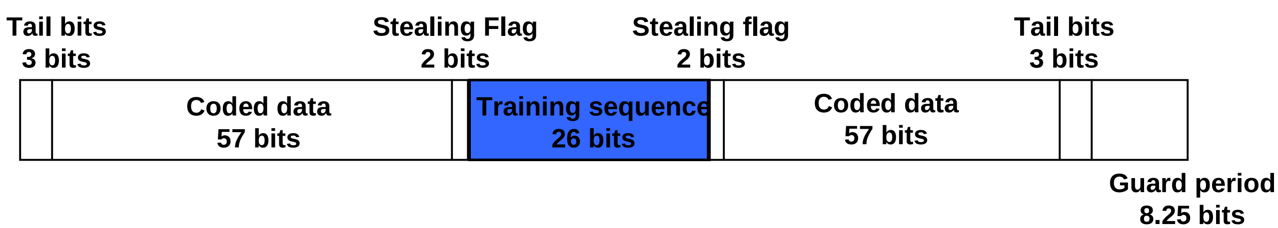
IMPLEMENTATION IN GSM

Correlation method

- 26 training bits in „Normal burst“
- 64 training bits in „Synchronization burst“

Normal burst



Chip length 48/13µs or 1.1km

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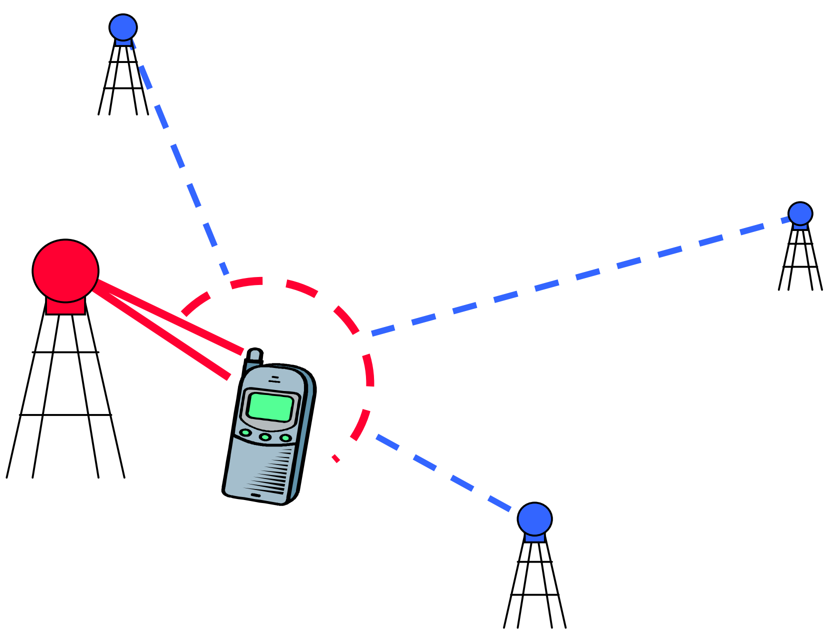
IMPLEMENTATION IN UMTS 1

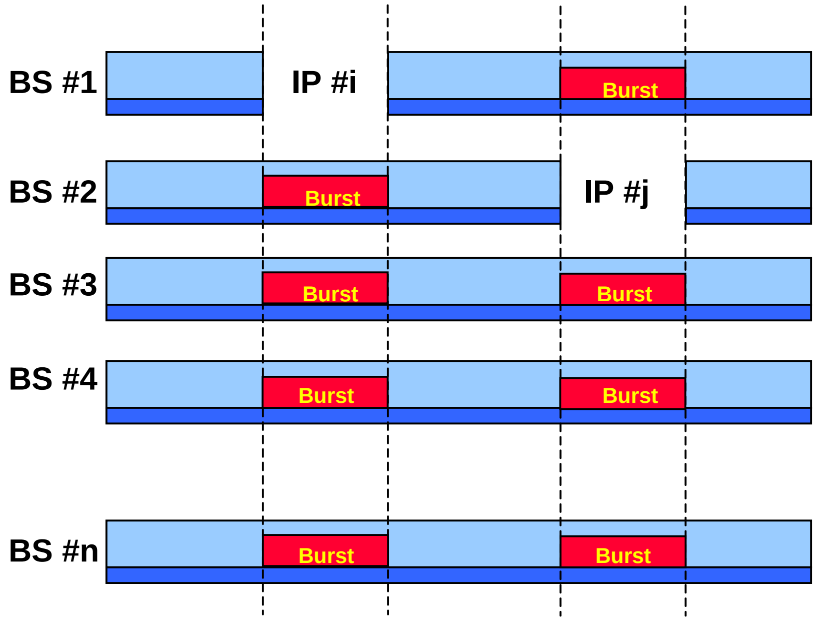
Channel access by CDMA

Problem: **Near-far effect**

Proposed solution:

Implementation of **idle periods**





IPDL

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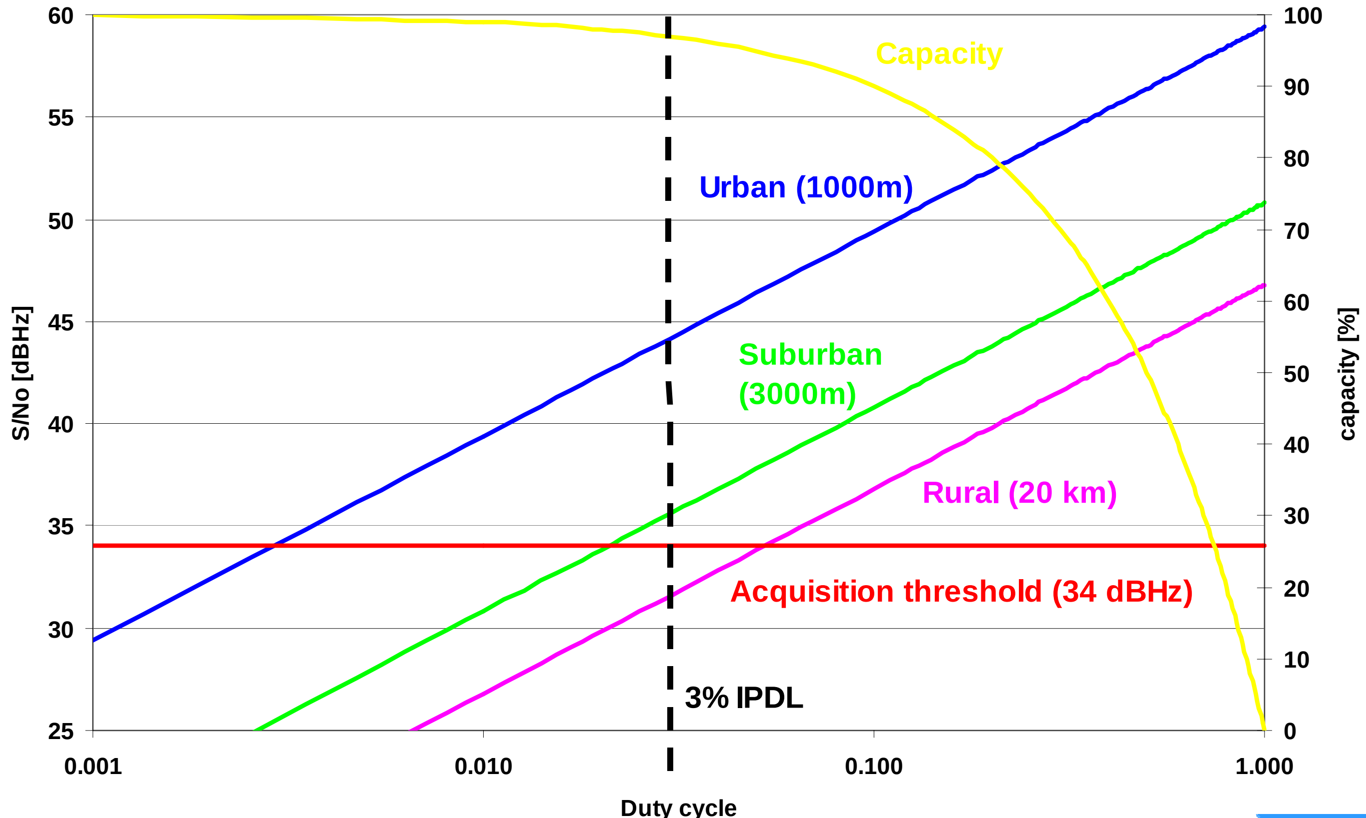
IMPLEMENTATION IN UMTS 2

Influence of IPDL on measurement noise



(Channel parameters according to a study of Samsung)

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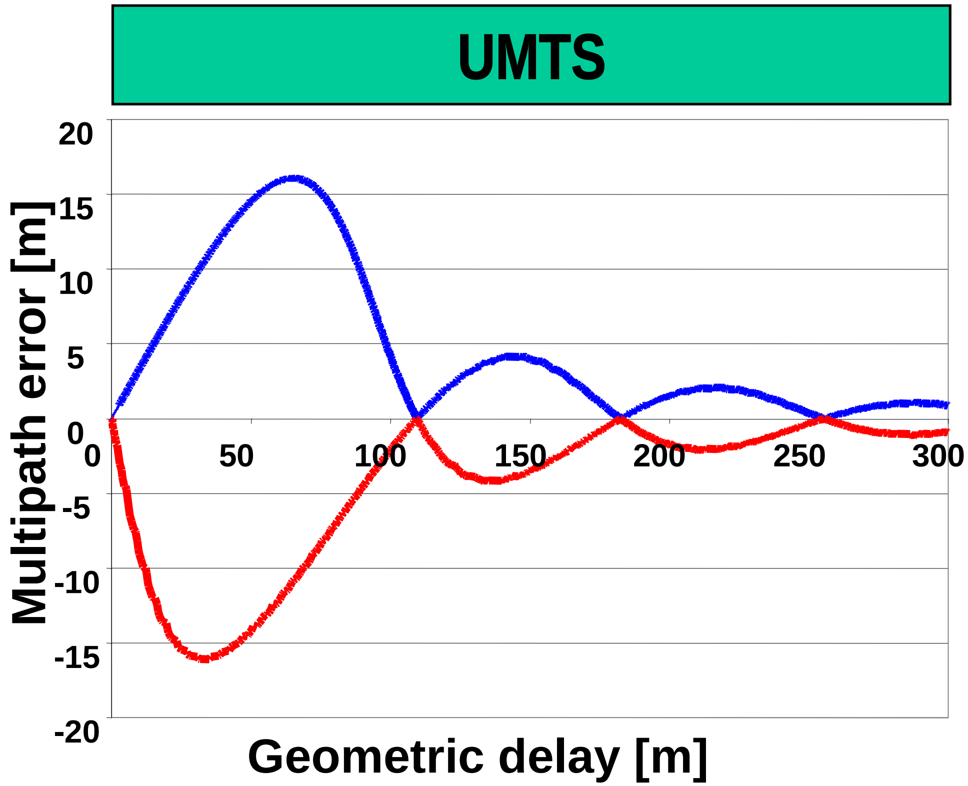
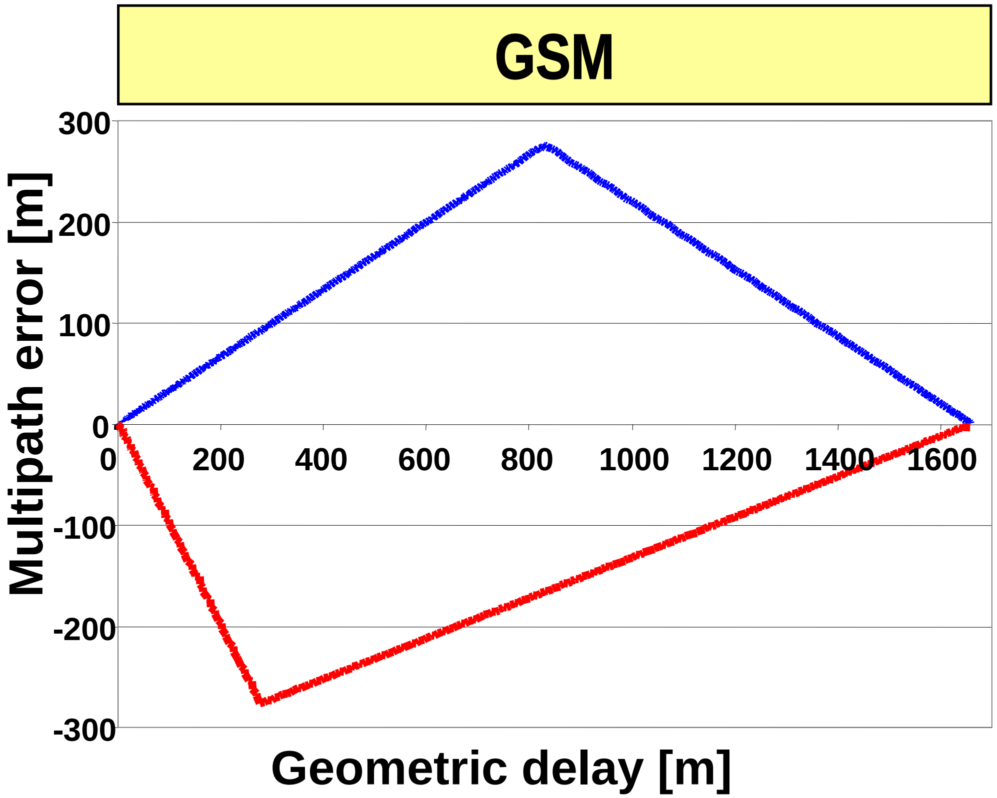
MULTIPATH ERRORS

Multipath error envelopes (Multipath errors due to superposition of a direct with an indirect signal, relative attenuation: 0.5)





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ERROR BUDGET

Error source	GSM	UMTS
Measurement noise	270 m	18 m
Multipath(*)	0-250 m	0-17 m
Troposphere	0.3-3 m	0.3-3 m
Synchronization of network/handset	3-6 m	3-6 m
Oscillator error	7.5 m	7.5 m
Total error (1 sigma)	**270-380 m**	**19-26 m**

(*) Not calculated with NLoS
NLoS causes errors due to multipath corresponding to the geometric delay

Position error = HDOP*Ranging error*2 (2dRMS)

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SIMULATIONS

- **Extension of IfEN´s SatNav End-to-End S/W simulator**
  – UMTS signal structure
- **Two test areas:**
  – Stuttgart downtown: High density of BSs, microcells
  – Oedekoven (suburb of Bonn): Rural BS structure
- **Calculations (only horizontal position possible):**
  – Number of “visible” (receivable) base stations
  – Geometry factors
  – Densification of MobCom network:
  – Number of necessary BSs for area-wide positioning
  – GNSS (GPS) vs. MobCom

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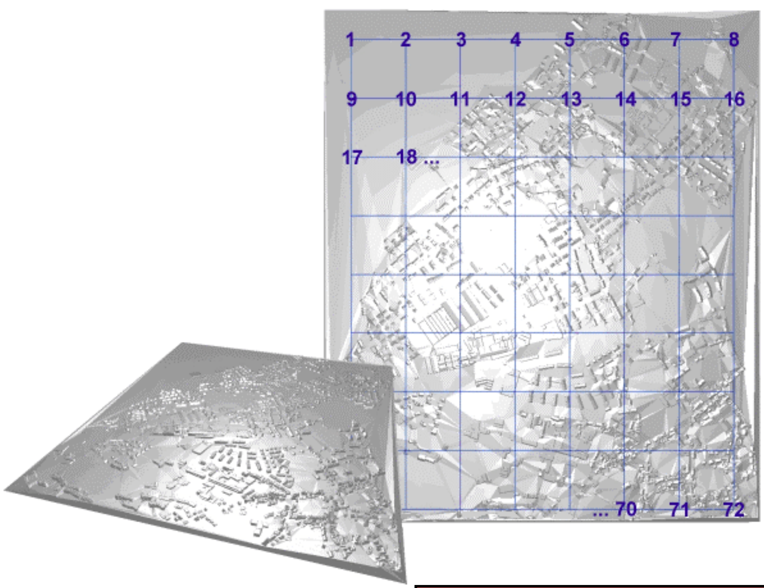
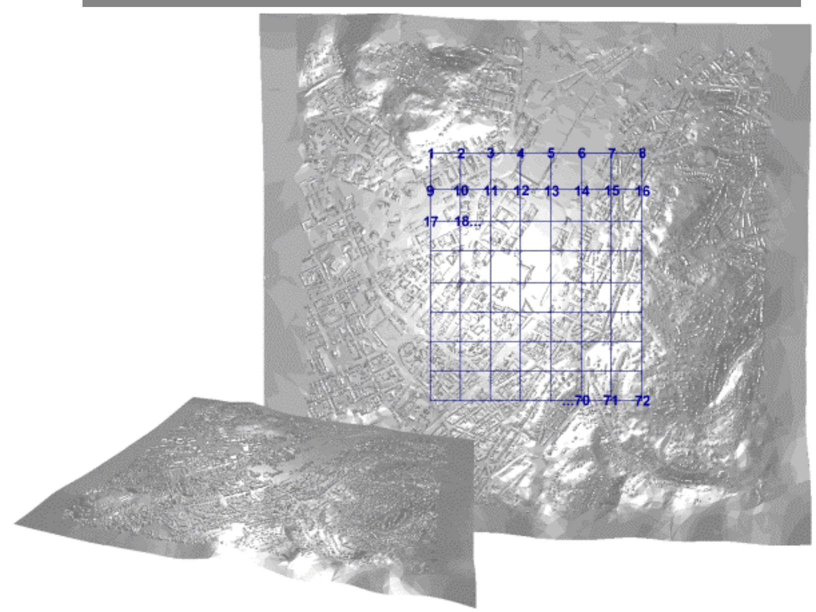
TEST AREAS

OEDEKOVEN (NEAR BONN)
1.5 km E-W, 1.8 km N-S
31 Base stations

DOWNTOWN STUTTGART
3.0 km E-W, 3.0 km N-S
178 Base stations





Grid: 200m x 200m, 1.5m above bottom

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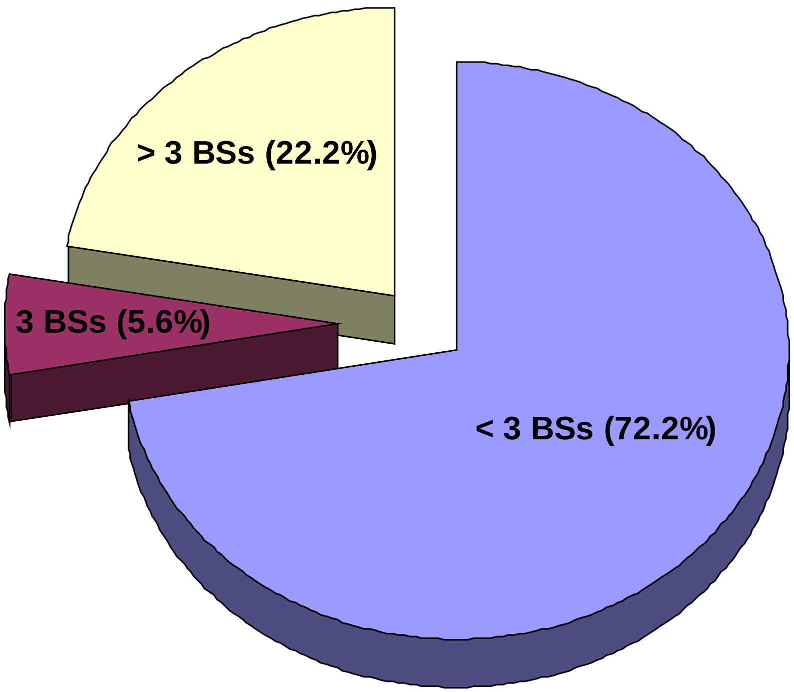
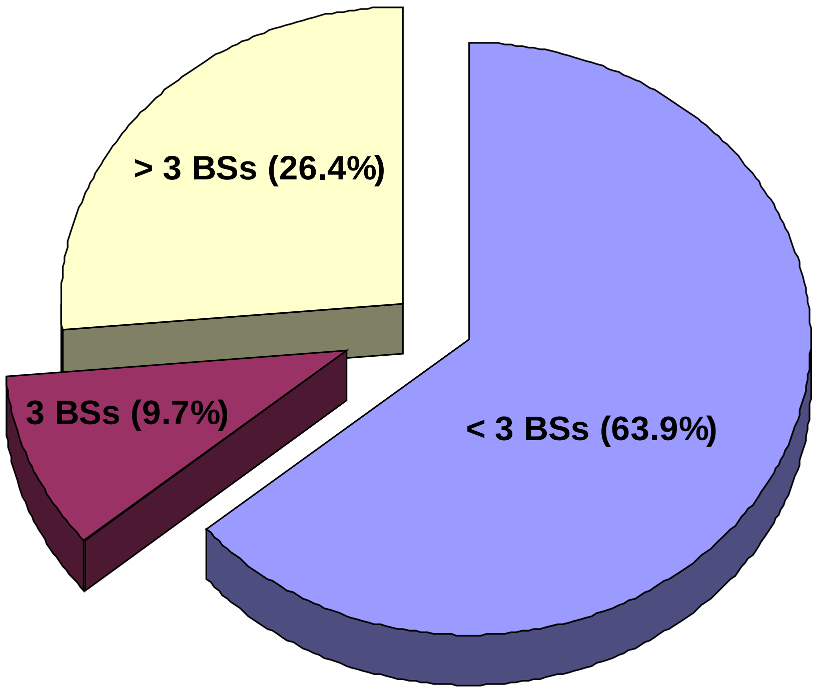
NUMBER OF RECEIVED BSs

Oedekoven



Stuttgart



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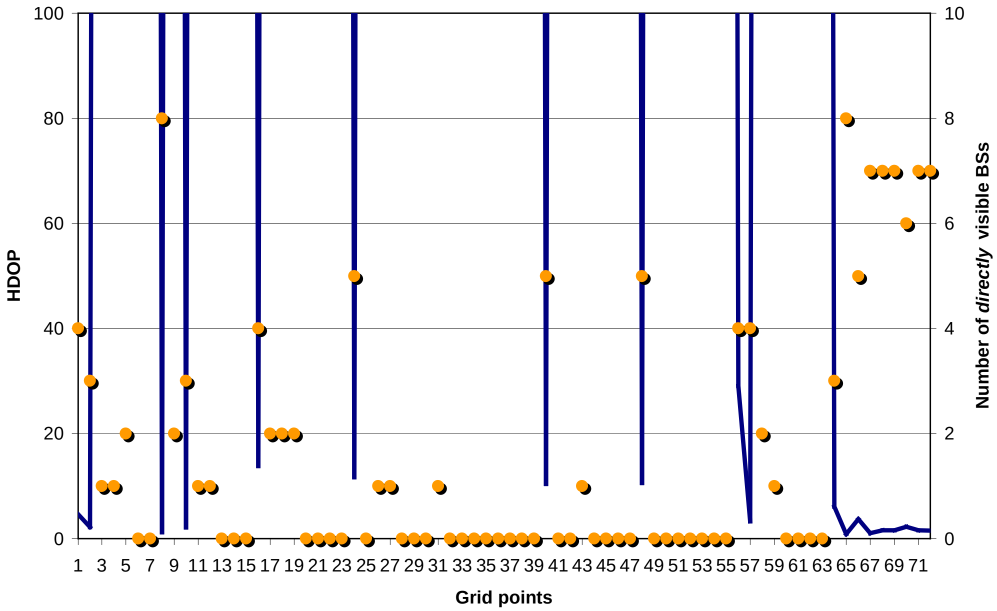
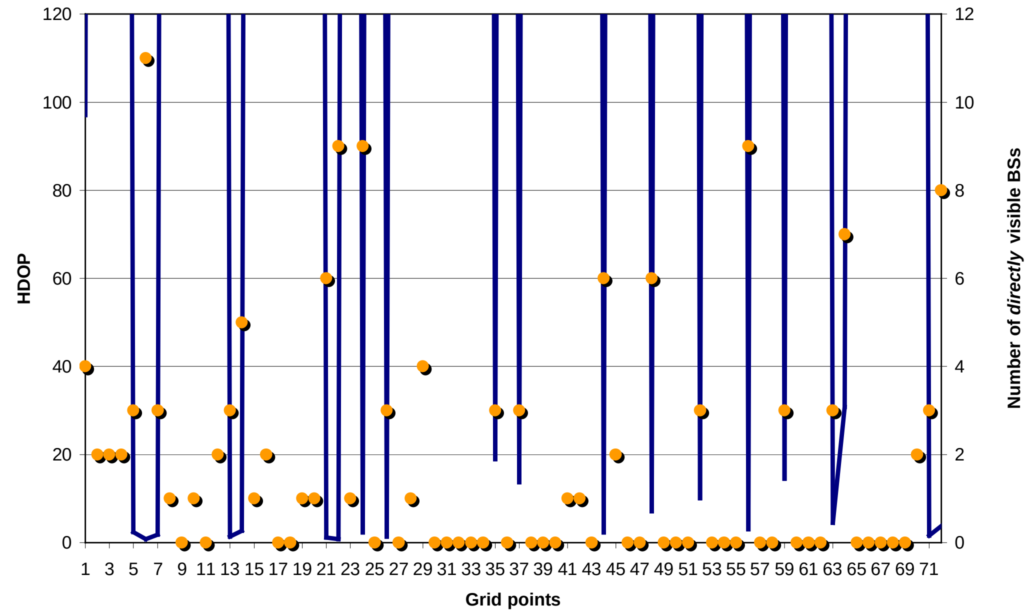
GEOMETRY FACTORS

Oedekoven



Stuttgart



Number of directly visible BSs
HDOP (mostly > 100)

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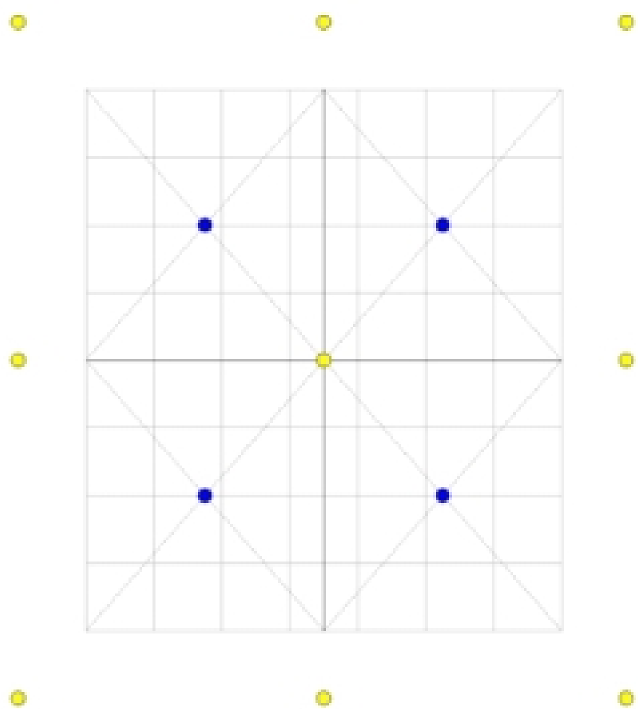
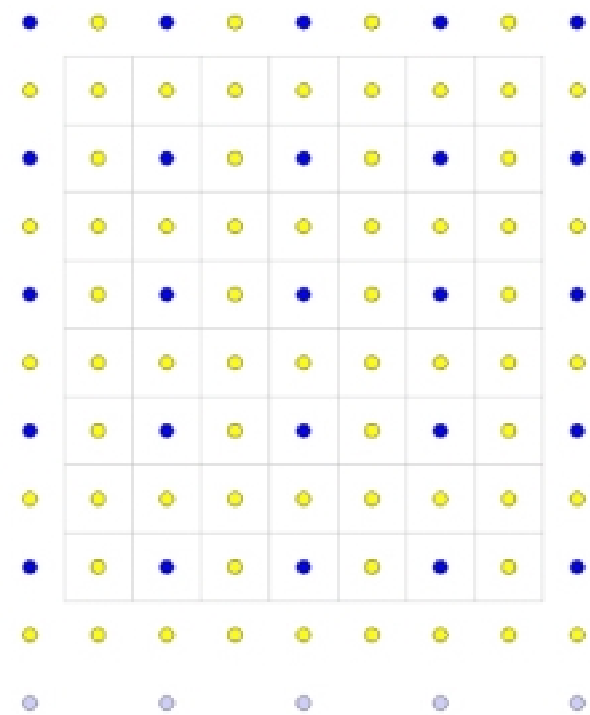
NETWORK DENSIFICATION (OEDEKOVEN) 1

Network structure (4+9)



Network structure (30+60)



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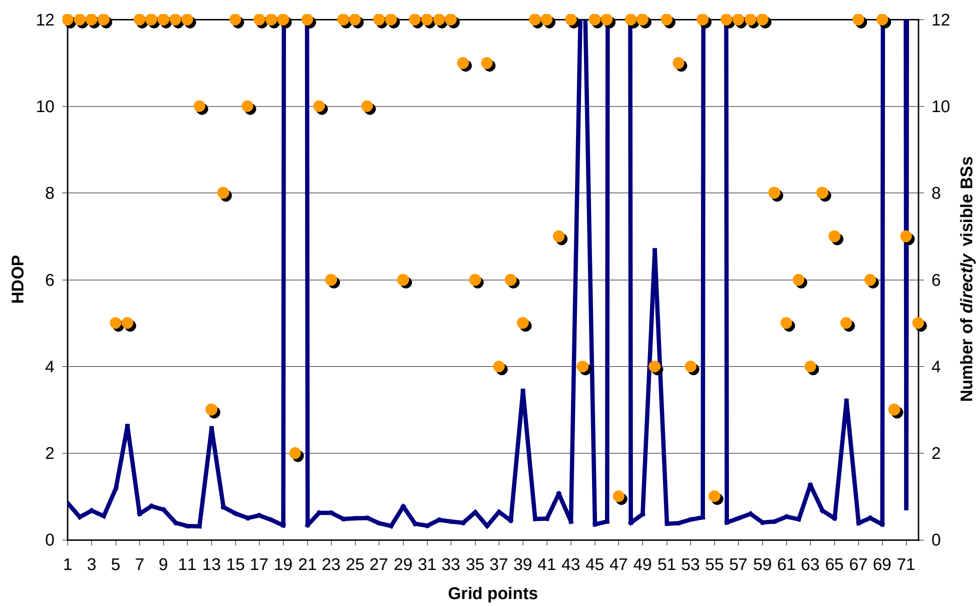
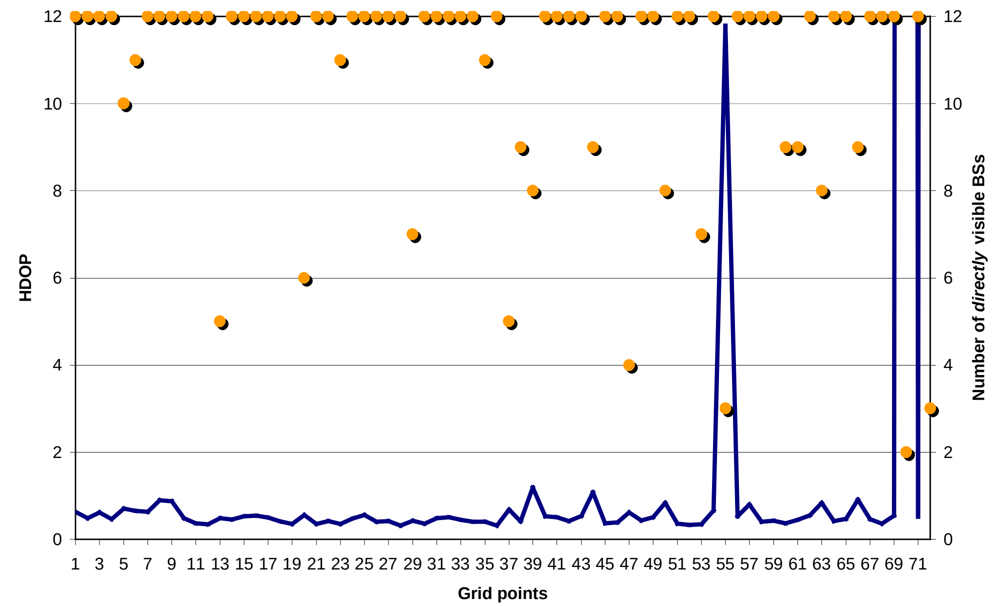
NETWORK DENSIFICATION (OEDEKOVEN) 2

Network structure (30)



Network structure (90)



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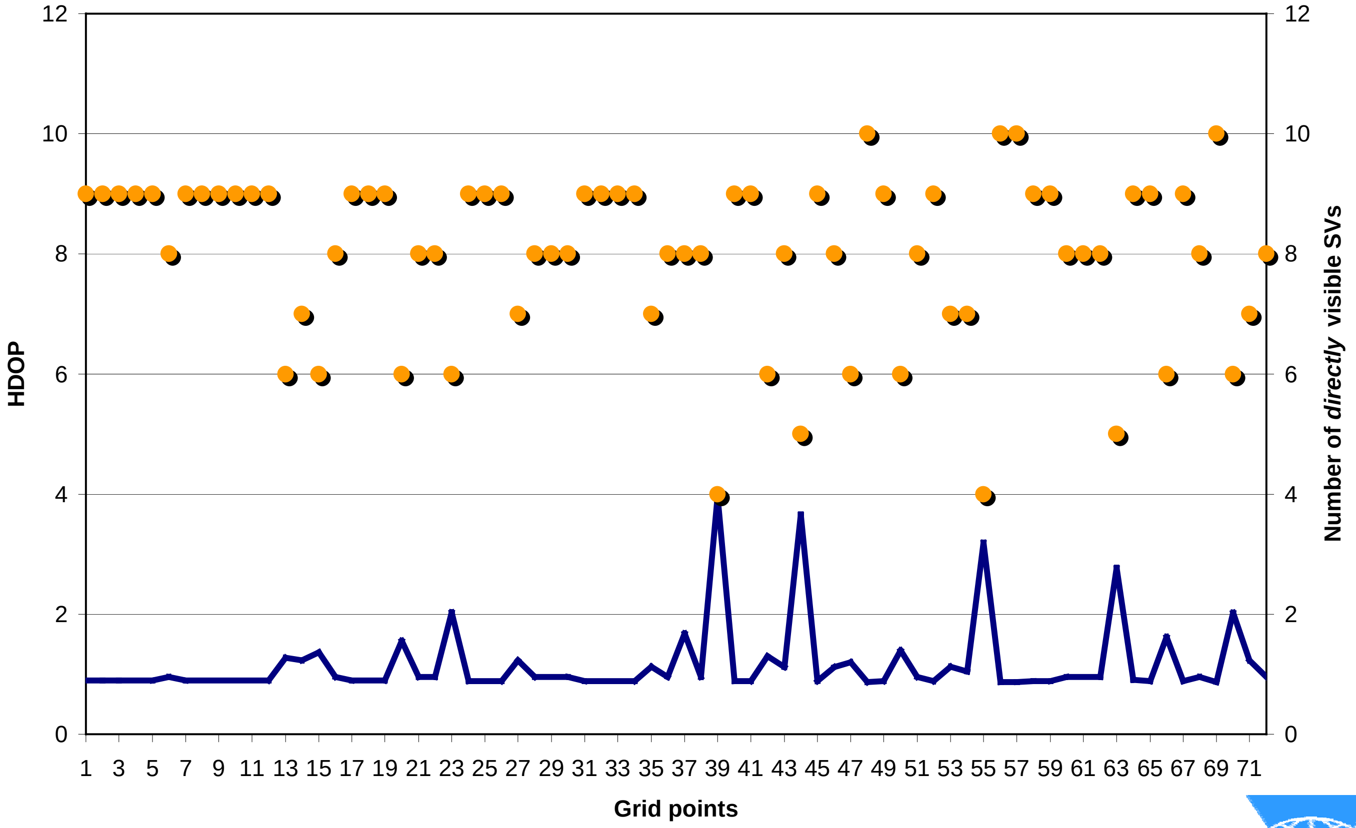
MOBCOM vs. GNSS (GPS)

Directly visible SVs and HDOP (for GPS)



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ROUGH ESTIMATE ON REQUIRED INFRASTRUCTURE

- Area-wide positioning using MobCom with accuracy < 50m
  - Increasing the **NUMBER of BSs with factor 2-3** due to geometry
  - 40 000 BSs x $ 50 000… $ 90 000 = **$ 2 … 3.6 billion**
- Synchronization of BSs (with higher accuracy) necessary
  - DCF77 and Quartz not sufficient (10^{-7}s) > Rubidium or GPS
  - 20 000 BSs x $ 5 000 = **$ 100 million**
- Equipment of MobCom network with Location Measurement Units (LMU)
  - Per 3-5 cells 1 LMU; approx. $ 7 000 … $ 10 000; 20 000 cells in D (Germany)
  - Investment costs for LMUs only D: **$ 50 ... 70 million**
- Total costs **2D positioning 100m (2drms) in D: $ 2.1 … 3.8 billion**
- For comparison: USA >$ 5 billion (www.fonefinder.com/Introduction.html)

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CONCLUSIONS

- Existing potential for 2D positioning in UMTS up to approx. 100m (2drms)
- Substantially limitations due to terrestrial geometry
- Total costs for LCS in existing network: > $ 150 million
- Total costs for area-wide LCS in D: $ 2.1 ... 3.8 billion per network
- Only for particular land user groups with limited requirements, not applicable for aero- and astronautics
- Integrity and continuity not yet considered

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