

Passive Tomography of a 3G Network: Challenges and Opportunities

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Motivations

- 3G environment (GPRS, UMTS) is evolving
 - User population growing
 - Terminal types and capabilities evolving
 - Usage patterns and billing schemes changing
 - New services emerging
 - Technological upgrades (GPRS→EDGE, UMTS→HSDPA)
- → Potential for macroscopic changes in traffic volume and geographical distribution
 - Need to continuously optimize / upgrade network resources
- To protect user experience, need to detect and fix local shortage of capacity (i.e. bottlenecks)
 - e.g. underdimensioned links, underdimensioned radio cells
- **Problem : how to detect such events in a cost-effective manner ??**

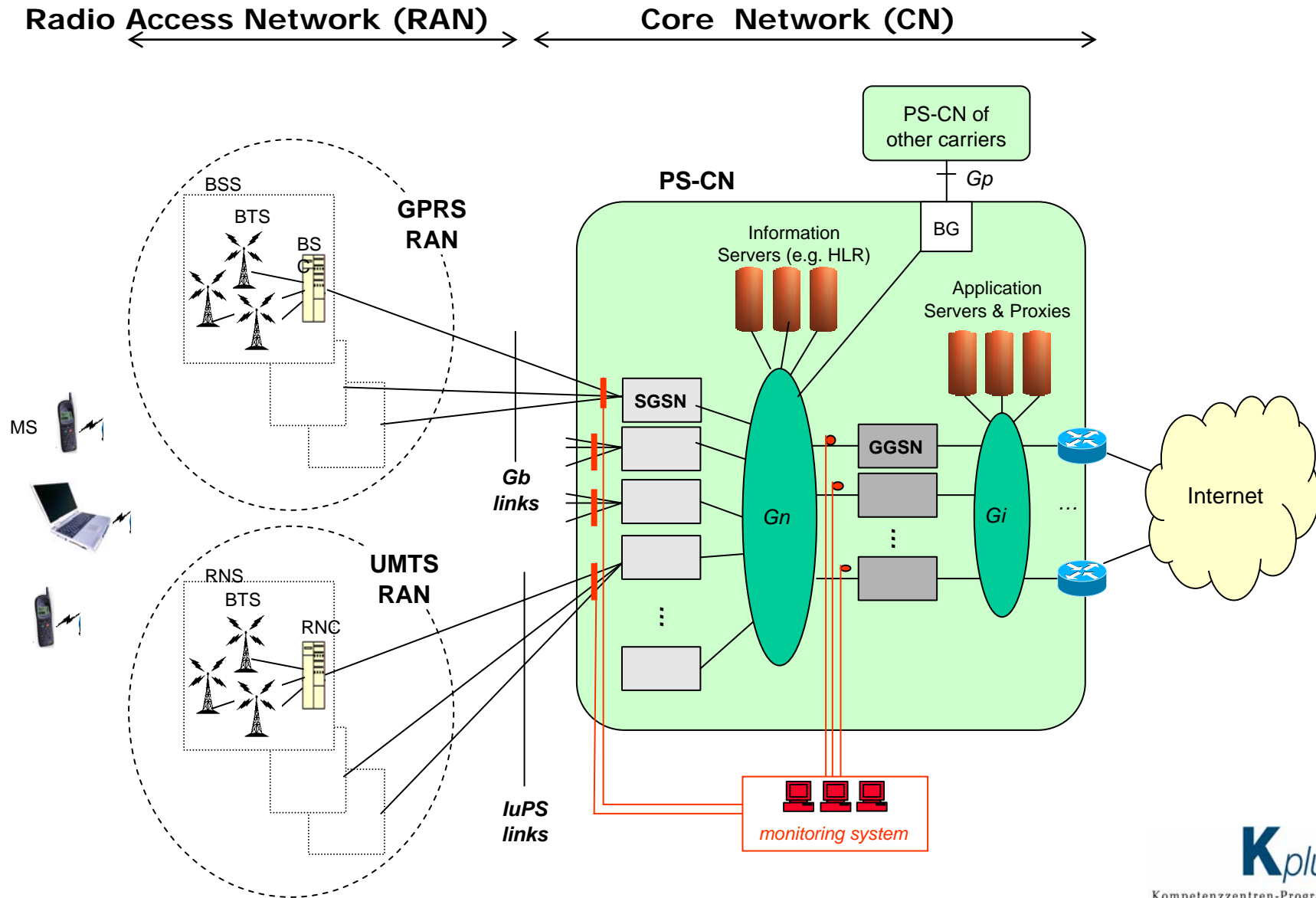
Motivations

- **The classical approach : ask the equipments**
 - Relay on output data from the equipments (logs, counters,..)
 - Need to **extract**, **gather** and **correlate** these data
- Main problem : **heterogeneity !!**
 - Extraction, gathering and correlation of such data is a huge headache !!!
 - Different kinds of equipments, SW releases, vendors, ...
 - Different data semantics, formats, ...
- Other limitations
 - **Reliability** : logs and counters might be not trustable
 - E.g. overload → malfunctioning -> wrong data
 - **Granularity** : counters might be too coarse-grained
 - Typically >5min average, per-MS counters not available, ...
 - **Performances** : activation of fine-grain counters and verbose logging might hinder equipment performance
 - **Availability** : important data might be simply not supported

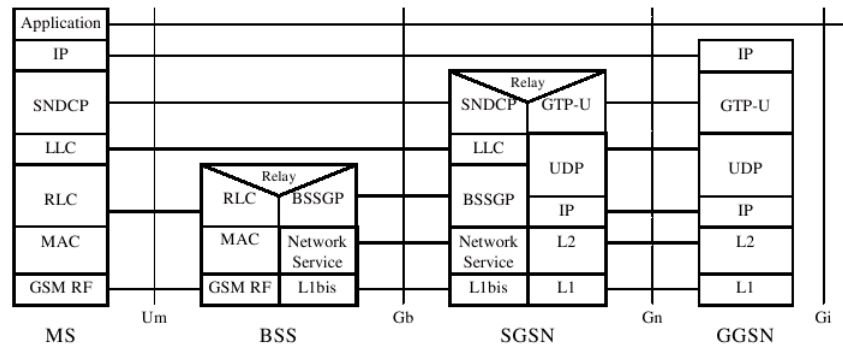
Motivations

- **The smart approach : ask the traffic !**
 - If there is a problem, the traffic will „feel“ it
 - Fine-grain monitoring of the traffic could reveal it
 - Basic concept: **large-scale passive network tomography**
- Requirements
 - Ability to collect high quality traffic traces
 - Need a suitable monitoring system
 - and deep knowledge about the network dynamics
 - Ability to „listen to the traffic“
 - E.g. Exploiting TCP closed-loop mechanisms
- Application to 3G networks
 - Peculiarities of 3G networks bring some more challenges ... ☹
 - e.g. very complex protocol stack
 - ... but also some advantages ☺
 - lots of info available at L2

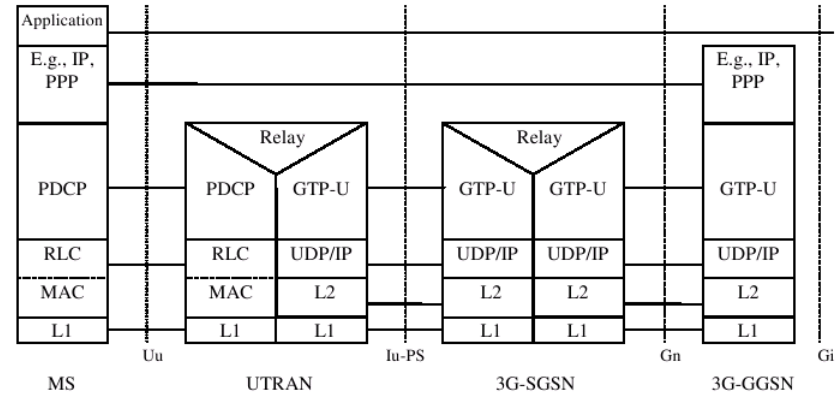
Background on 3G networks: topology



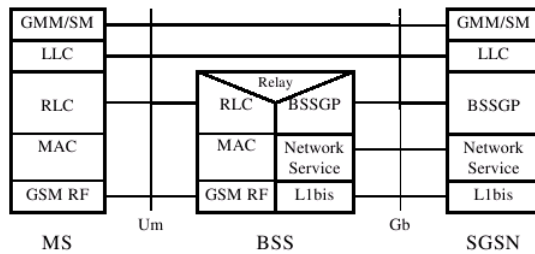
Background on 3G networks: protocol stacks



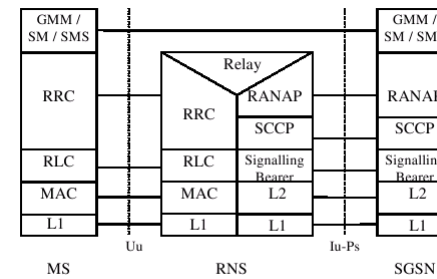
GPRS user plane



UMTS user plane



GPRS control plane



UMTS control plane

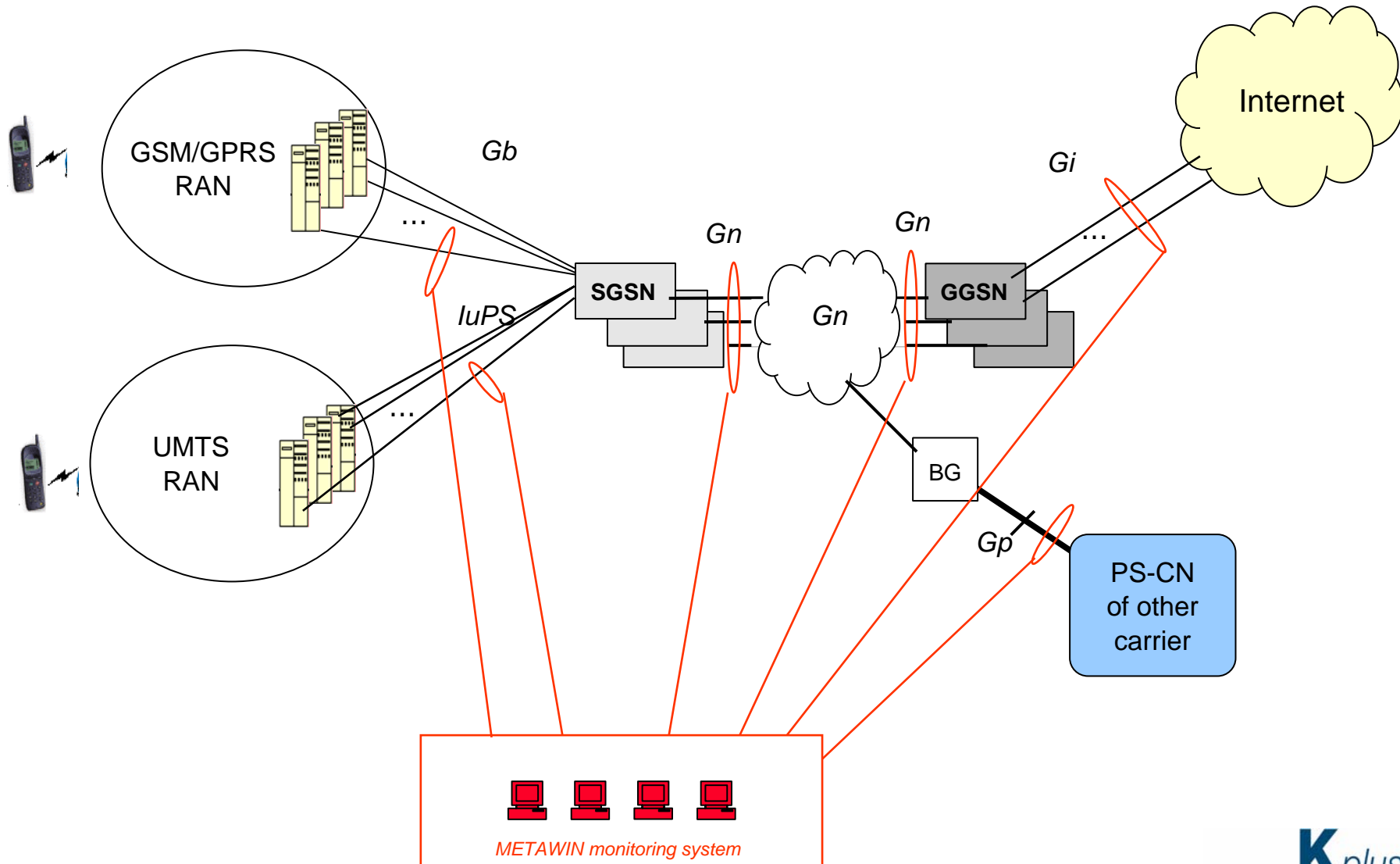
Passive Tomography Applied to 3G

- Network topology highly hierarchical (tree-like)
 - Core Network equipments (SGSN, GGSN) located at few physical sites 😊
 - Monitoring the CN links (Gn Gb, IuPS) near the SGSN/GGSN
 - Path symmetry 😊
 - Single monitoring point can capture traffic in both direction
- 3GPP protocol stack is thick and complex
 - Need to parse and interpret lots of L2 protocols 😞
- Very complex interactions between Mobile Stations and network
 - e.g. for Mobility Management, Resource Management,..
 - A wealth of information can be extracted from 3GPP L2 😊
 - e.g. originating cell, unique MS identifier, MS state, ...
 - To extract such information, the monitoring system must be able to „follow“ these interactions and keep state (→ higher complexity)
- Strong privacy requirements
 - All subscriber-related fields must be hashed on-the-fly (e.g. IMSI)
 - Payload cutted away or hashed

The METAWIN monitoring system

- METAWIN was a research project carried on in collaboration between scientific and industry partners
 - Telecommunication Research Vienna (ftw.)
 - mobilkom austria AG & Co KG
 - Kapsch CarrierCom
 - Technical University of Vienna
- During the project a prototype of a large-scale monitoring system tailored for 3G networks and with advanced features was developed (and deployed)
- It is now being used for further research in
 - Anomaly detection
 - Large-scale performance monitoring
 - **3G tomography (this work)**

The METAWIN monitoring system



The METAWIN monitoring system

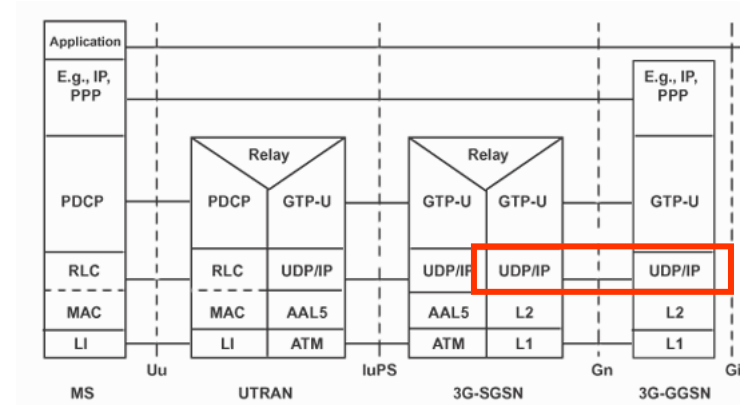
- Features of the METAWIN monitoring/analysis system
 - **Large-scale m/a**
 - capture all traffic
 - **Complete m/a**
 - capture all interfaces: allows **end-to-end** analysis and correlation
 - **Cross-layer m/a**
 - Capture and parse all protocol layers: allows **cross-layer** analysis and correlation
 - **Fine granularity**
 - Can decompose into any dimension: protocol, type-of-message, specific field values, etc.
 - Can track down to **individual IMSI, cells/RA**, etc.
 - Can count at sub-second time granularity
 - **Always-on (24h/7d)**
 - **Long-term storage**
 - weeks
 - Built-in data processing and automatic / proactive reporting
 - Ongoing work

Passive Tomography in 3G

- Listen to TCP
 - Most of the traffic is TCP
 - Closed-loop -> performance depends on the end-to-end path conditions
 - Looking at TCP flows at *any point* might infer performance degradation *somewhere* along the path
 - **Approach 1** : signal analysis of aggregate rate
 - **Approach 2** : frequency of TCP retransmissions (RTO) and/or RTTs
 - Degradation common to all flows along one path is a strong indication of problems along the path
 - Fits well 3G networks: tree-based topology, path symmetry
- **Need knowledge about the traffic paths !**
 - **In 3G such information can be squeezed out from 3GPP L2 protocols !**
 - Exploiting METAWIN advanced features
 - Definition of Sub-Aggregate X (SA X): all traffic routed over X
 - X can be a network node (e.g. SGSN, RNC), a physical site, a radio cell

Discriminating Sub-Aggregates

- Monitor Gn links near the GGSN (GPRS and UMTS)
 - The IPaddr below the GTP layer tells which SGSN each packet is going to / coming from
 - Extract per-SGSN and per-site SAs



- Tracking PDP-context activations and associated GTP tunnel tell associations packet-IMSI, packet-APN, ...
 - PDP attributes are exchanged during PDP-activation phase

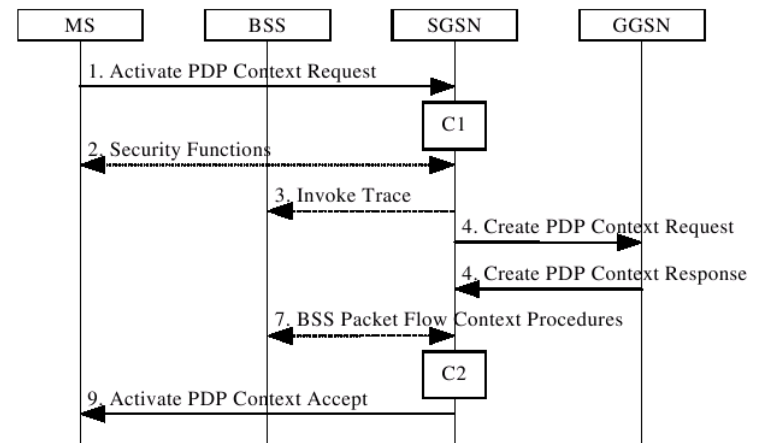


Figure 63: PDP Context Activation Procedure for A/Gb mode

Discriminating Sub-Aggregates

- Monitor Gb links near the SGSN (for GPRS)
 - Stateful tracking of 3GPP signaling messages enables maintenance of packet-to-MS and MS-to-cell associations
 - Enables SA discrimination per-cell, per-RoutingArea, per-BSC/RNC,...

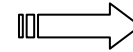
- Monitor IuPS links near the SGSN (for UMTS)
 - Monitor IuPS links near the SGSN for UMTS
 - Similar to Gb, but involves different protocols
 - Resolution granularity is limited to Routing Area ☹
 - A Routing Area is a collection of cells, similar to Location Area in GSM

Recent results

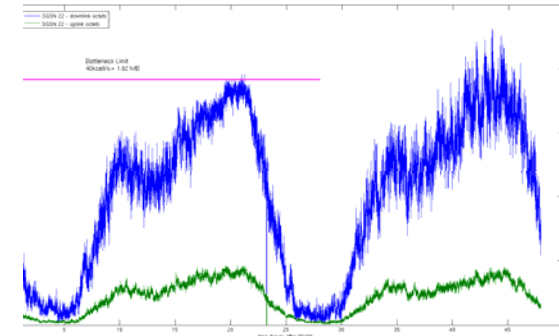
- Proof-of-concept: analysis of per-SGSN SAs captured on Gn (near the GGSN) has revealed a capacity bottlenecks on a remote Gn link

- **Approach 1: by signal analysis of aggregate rate**

- [F. Ricciato, W. Fleischer, *Bottleneck Detection via Aggregate Rate Analysis: A Real Case in a 3G Network*, IEEE/IFIP NOMS'06, Vancouver, April 2006]



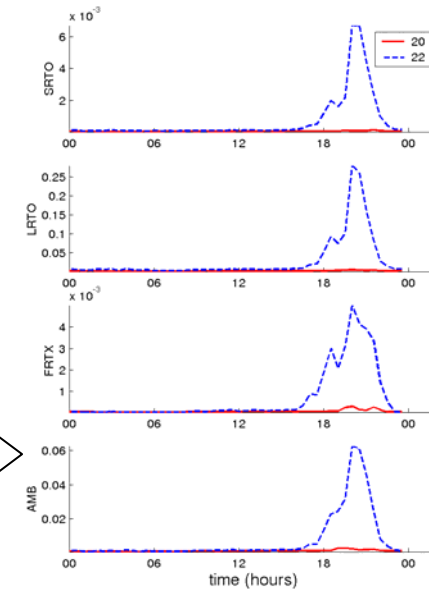
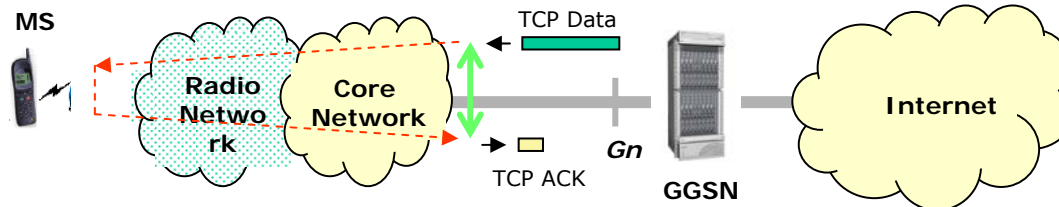
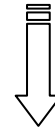
rate (10s bins)



time

- **Approach 2: by estimated frequency of TCP retransmission timeouts (RTO) and round-trip-time (RTT)**

- Based on a modified version of tcptrace
- [F. Ricciato, F. Vacirca, M. Karner, *Bottleneck Detection In UMTS Via TCP Passive Monitoring: A Real Case*, Proc. of ACM CoNEXT'05, October 24-27, 2005, Toulouse]



Ongoing work 1/2

- **GPRS/EDGE: per-cell RTT/RTO measurements**
 - Smaller SAs, less aggregation, less samples
 - Few MS active in each cell at each time
 - We expect Approach 2 (TCP RTO / RTT) to scale better than Approach 1 (rate analysis)
 - Goal/1 : discriminate TCP degradation due to cell conditions from MS-specific conditions
 - Goal/2 : identify *recurrent* degradation (over different time-periods)
- Current status:
 - SA discrimination on Gb completed
 - Preliminary RTO/RTT measurements on past sample traces (following slides)
 - Extensive measurements on recent trace planned during May

Ongoing work 2/2

- **UMTS/HSDPA: per-RNC and per-Routing-Area RTT/RTO**
 - Per-cell SA discrimination from IuPS traffic currently not possible (limited to per-Routing-Area)
 - We expect Approach 2 (TCP RTO / RTT) to scale better
 - Main problem : infer presence of troubles in some cell from measurements at the RA level (e.g. clusters of high RTO/RTT)

- **Current status:**
 - SA discrimination on IuPS completed
 - Preliminary RTO/RTT measurements on sample traces planned in April/May

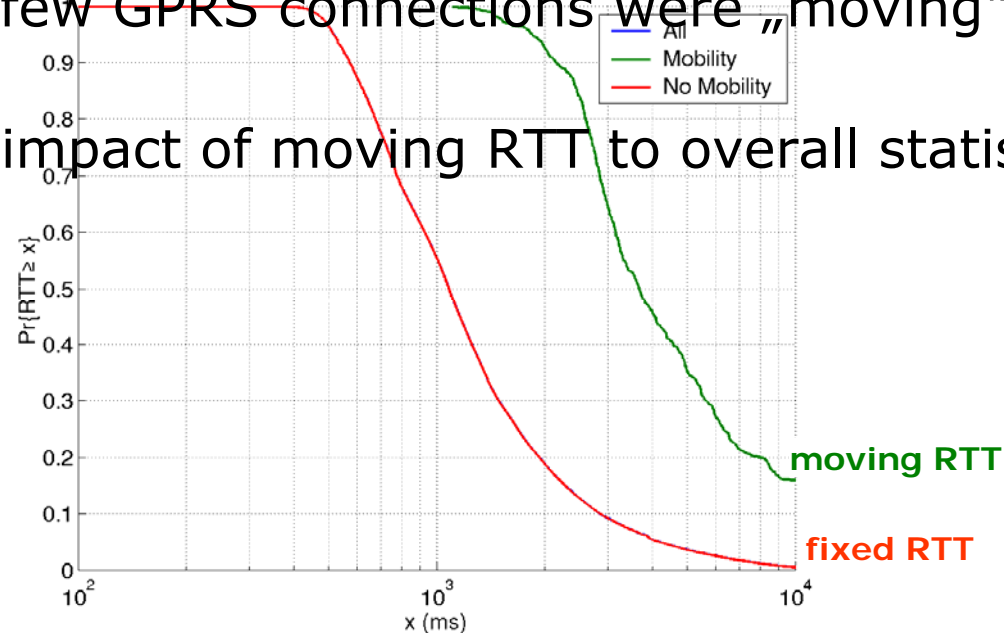
Preliminary results (GPRS only)

- Some MS move during traffic activity (cell handover: HO)
 - E.g. downloading email in a train (many HO)
 - E.g. cell reselection due to radio fluctuation (one or few HO)
- Expectedly worst performance during HO
 - Higher RTT, higher RTO (?)
- Need to divide RTT/RTO statistics for the two classes:
 - „moving“ vs. „fixed“ traffic
 - RTT discrimination based on cell information for DATA/ACK pair
 - $\text{cell}(\text{DATA}) \neq \text{cell}(\text{ACK}) \rightarrow$ „moving“ RTT sample
 - $\text{cell}(\text{DATA}) = \text{cell}(\text{ACK}) \rightarrow$ „fixed“ RTT sample
 - RTO more complex: compare $\text{cell}(\text{P1}) = ? \text{cell}(\text{P2})$
 - P1 = last packet seen *before* the RTO event
 - P2 = first correct packet *after* the RTO event
- The same data are the basis for a large-scale assesment of the performance loss in GPRS due to HOs

Preliminary results (GPRS only):

„fixed“ vs „moving“ RTT ccdf

- CCDF of RTT samples (10.10.2005 - 20⁰⁰-21⁰⁰h, no EDGE yet)
 - Median of „moving RTT“ was ~3sec higher
- The volume of „moving traffic“ << „fixed traffic“
 - Relatively few GPRS connections were „moving“ (in Oct`2005)
 - Negligible impact of moving RTT to overall statistics



Preliminary results (GPRS):

(per-cell measurements, 20⁰⁰-21⁰⁰h for 3 days, only „fixed“ traffic)

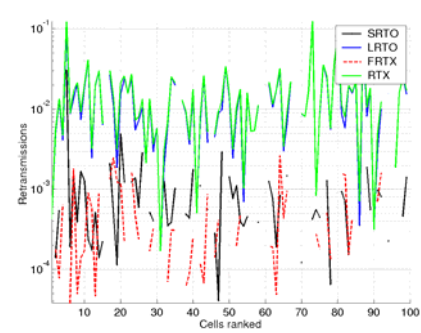
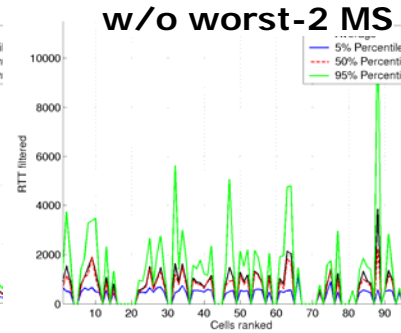
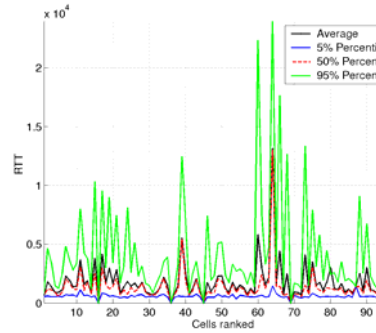
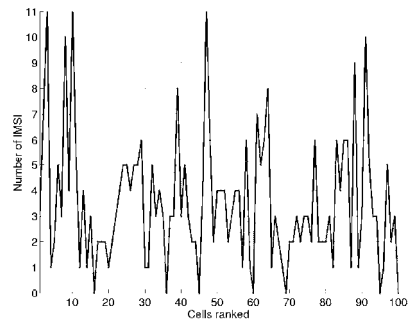
active MS seen in the cell

RTT percentiles

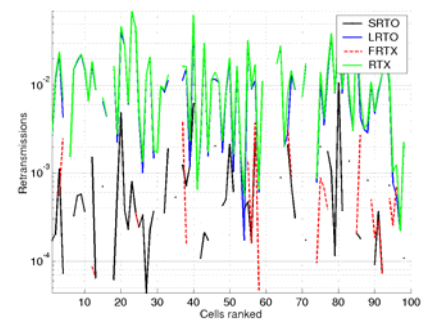
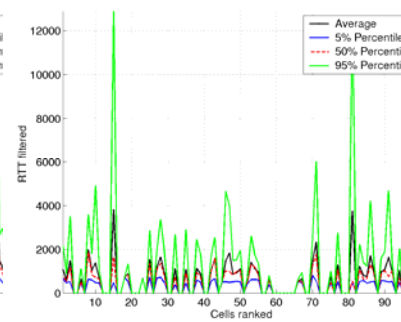
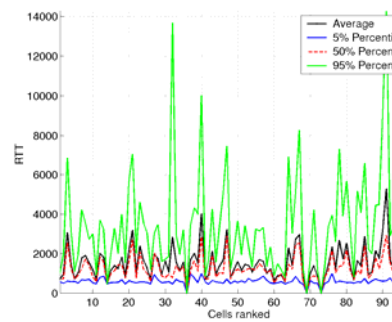
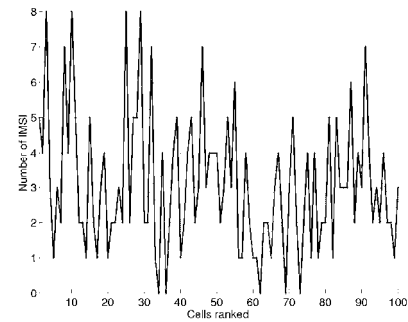
RTT percentiles
w/o worst-2 MS

estimated RTO frequencies

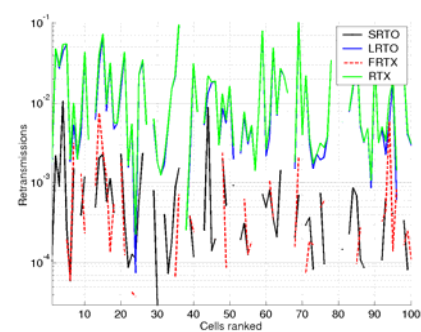
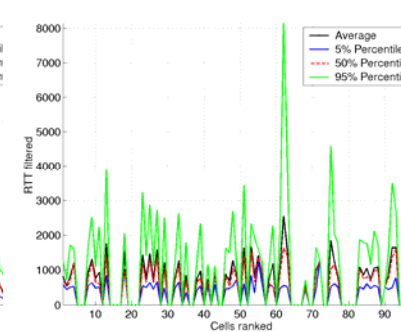
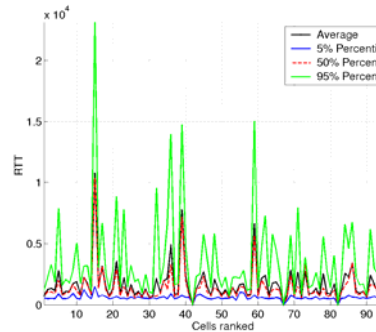
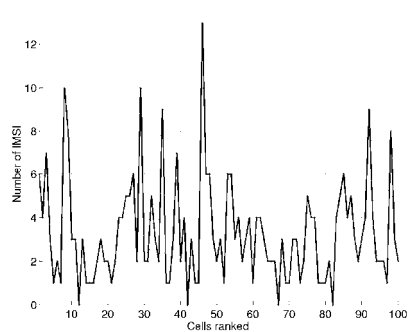
17.10.05



20.10.05



22.10.05



Summary and references

- The vision
 - use TCP RTT/RTO measurement from passive monitoring at few sites in the Core Network ...
 - ... to detect/infer recurrent problems in the Radio Access Network
 - ... as input the network (re)optimization process
- Current status:
 - Trace capturing and recovery of packet-IMSI / IMSI-cell associations
 - Done, using the METAWIN monitoring system
 - RTT/RTO extraction
 - Done, using modified version of tcptrace for off-line analysis
 - Extracting preliminary data:
 - Done for GPRS, exploration is ongoing. tbd for UMTS
 - Formalization of inference problem, collection of long-term data
 - ... the next steps
- More on METAWIN and DARWIN projects
 - <http://userver.ftw.at/~ricciato/darwin>
 - Contact person: Fabio Ricciato, ftw. (ricciato@ftw.at)