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 ??**

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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 : **heterogenity** !!
  - Extraction, gathering and correlation of such data is a hige 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 → misfunctioning -> 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

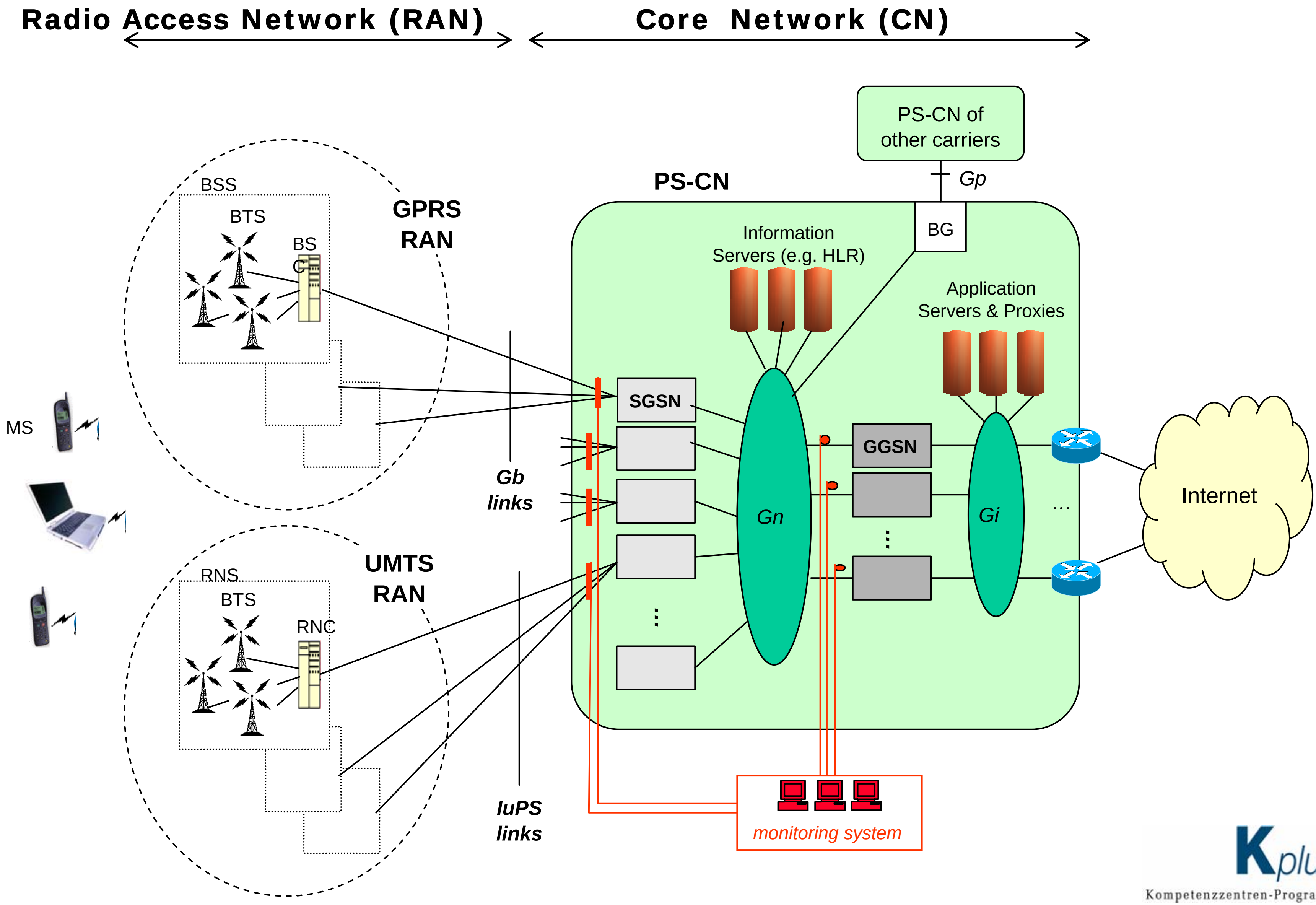
Motivations

- **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



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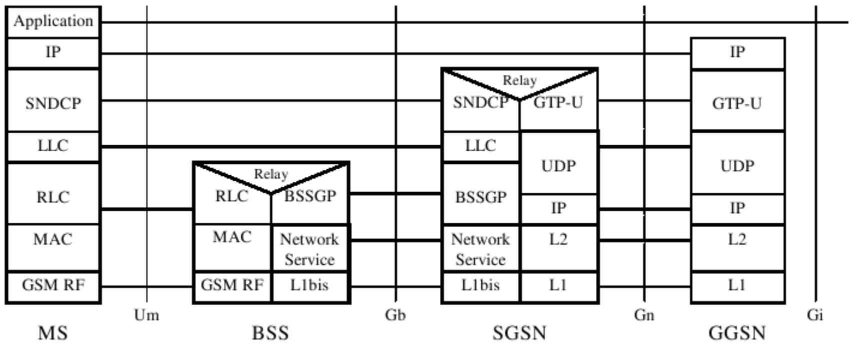
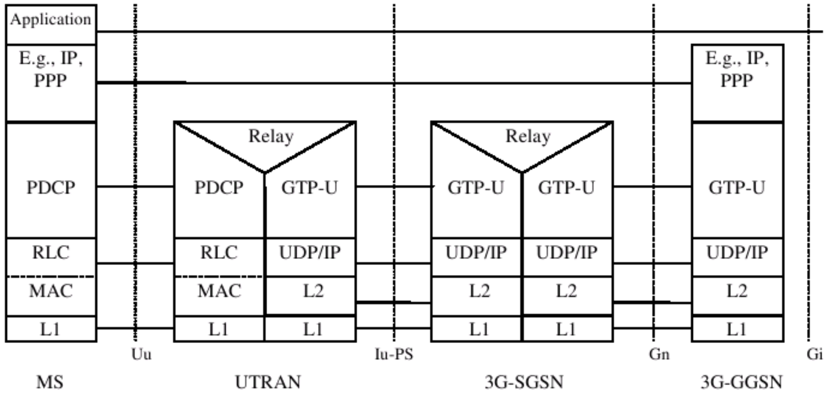
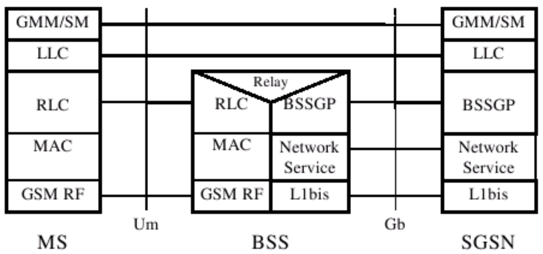
Background on 3G networks: protocol stacks



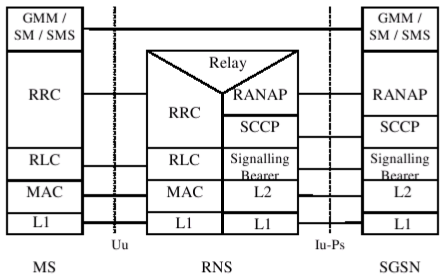
GPRS user plane



UMTS user plane



GPRS control plane



UMTS control plane

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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

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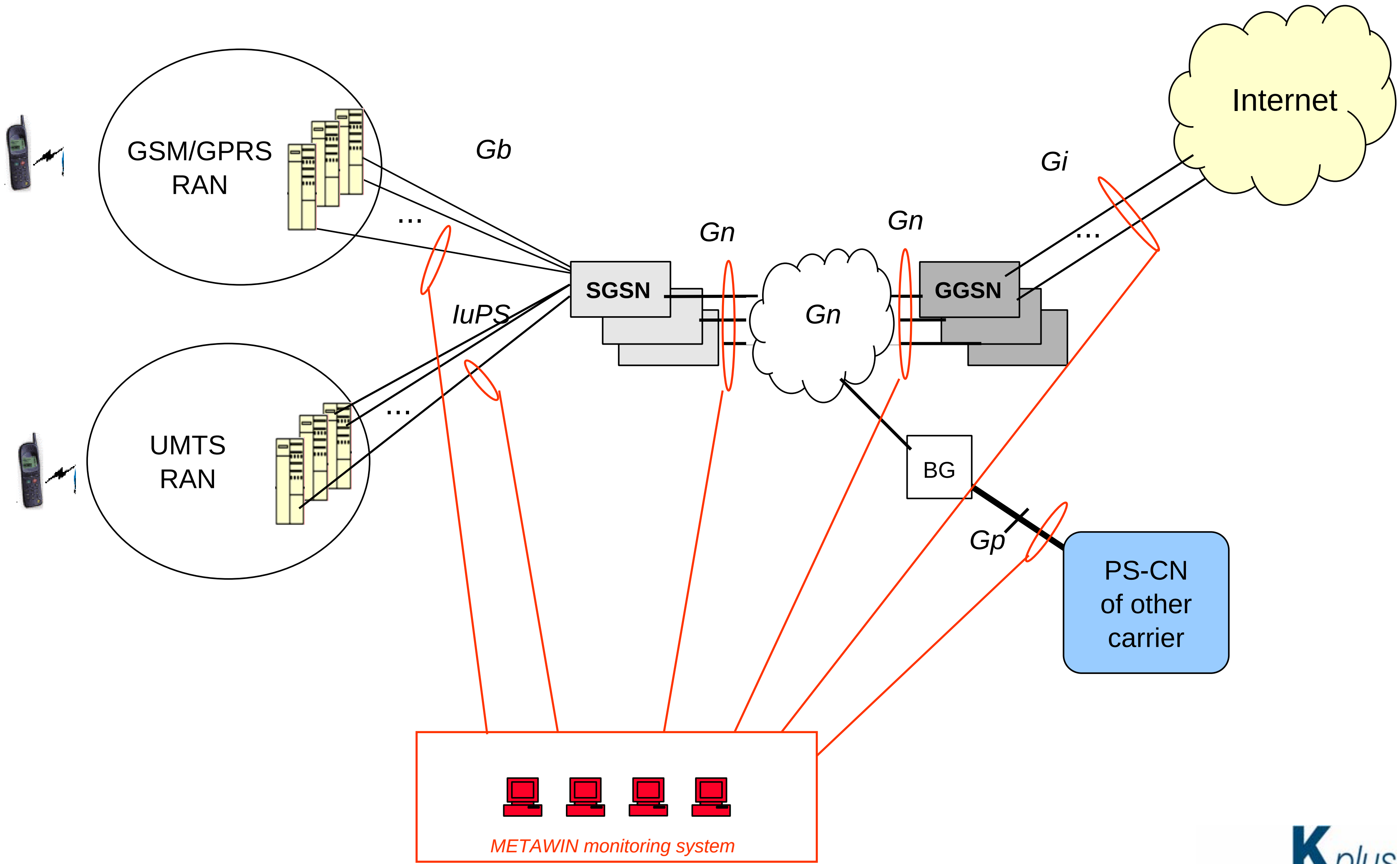
The METAWIN monitoring system

- 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



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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

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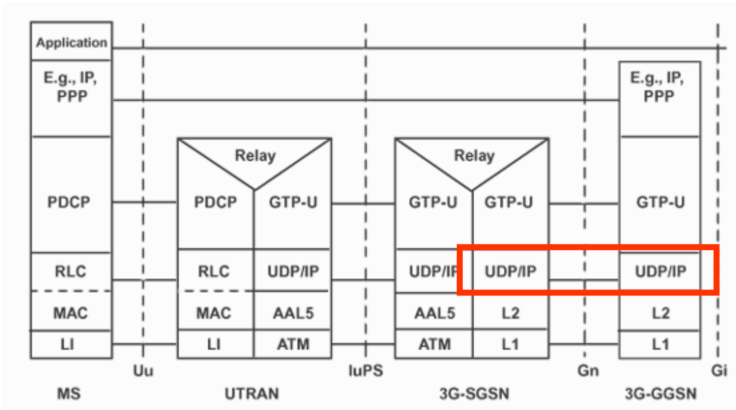
Discriminating Sub-Aggregates

- Monitor Gn links near the GGSN (GPRS and UMTS)
  - The <u>IPaddr below the GTP layer</u> 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

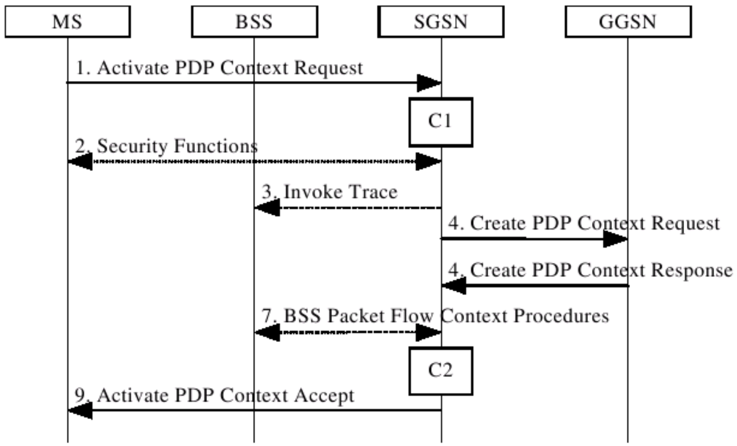


Figure 63: PDP Context Activation Procedure for A/Gb mode

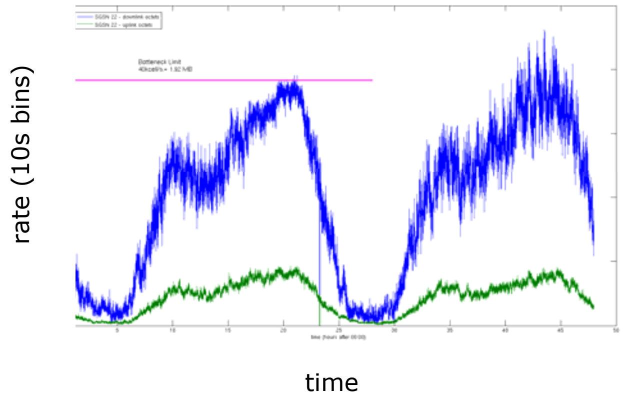
Discriminating Sub-Aggregates

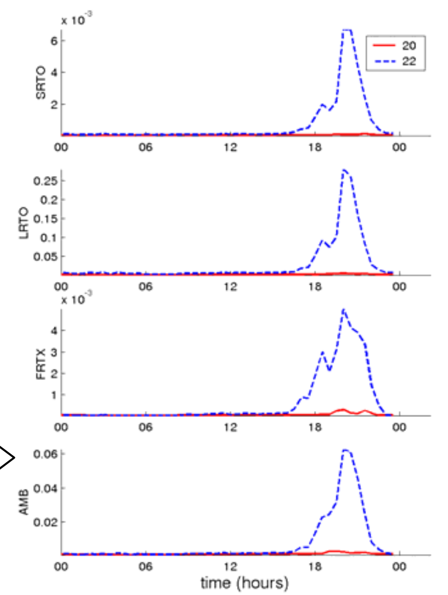
- Monitor Gb links near the SGSN (for GPRS)
  - Stateful tracking of 3GPP signaling messages enables maintainance of packet-to-MS and MS-to-cell associations
  - Enables SA discrimination per-cell, per-RoutingArea, per-BSC/RNC,...

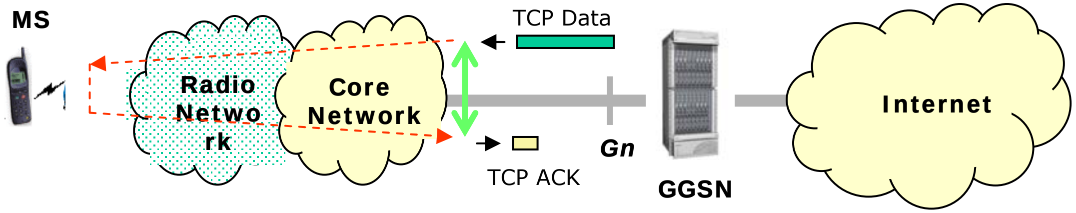
- Monitor IuPS links near the SGSN (for UMTS)
  - Monitor IuPS links near the SGSN for UMTS
  - Similar to Gb, but involves different protocols
  - Resolution granularity is limited to Routing Area ☹
    - A Routing Area is a collection of cells, similar to Location Area in GSM

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]*
  - **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 mesaurements 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
    - cell(DATA)≠cell(ACK) → „moving" RTT sample
    - cell(DATA)=cell(ACK) → „fixed" RTT sample
  - RTO more complex: compare cell(P1)=?cell(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

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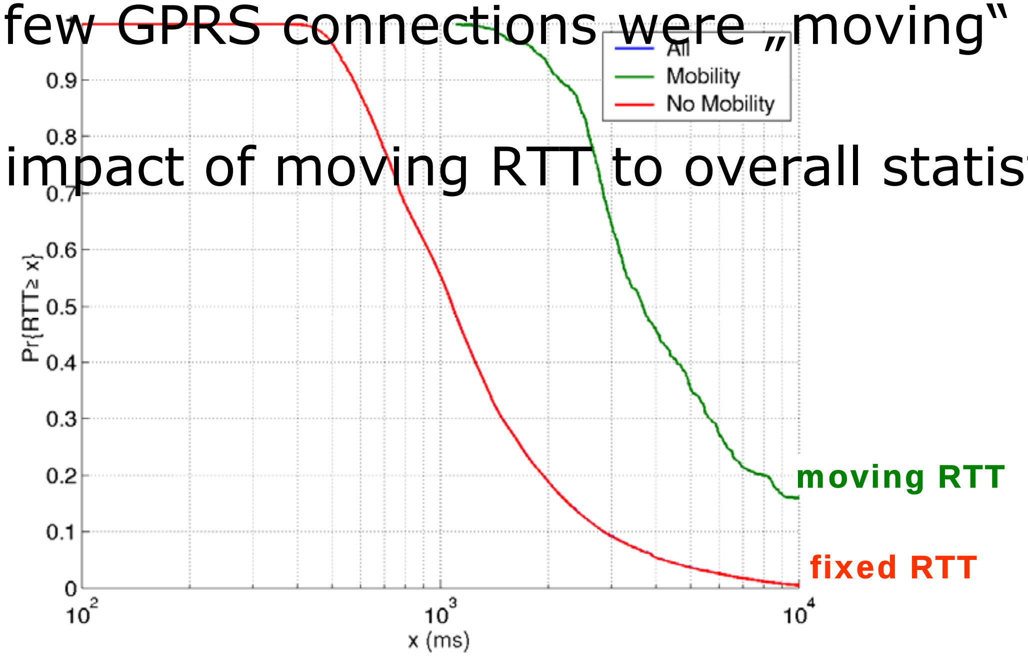
Preliminary results (GPRS only):

„fixed" vs „moving" RTT ccdf

- CCDF of RTT samples (10.10.2005 - 20^{00}-21^{00}h, 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):

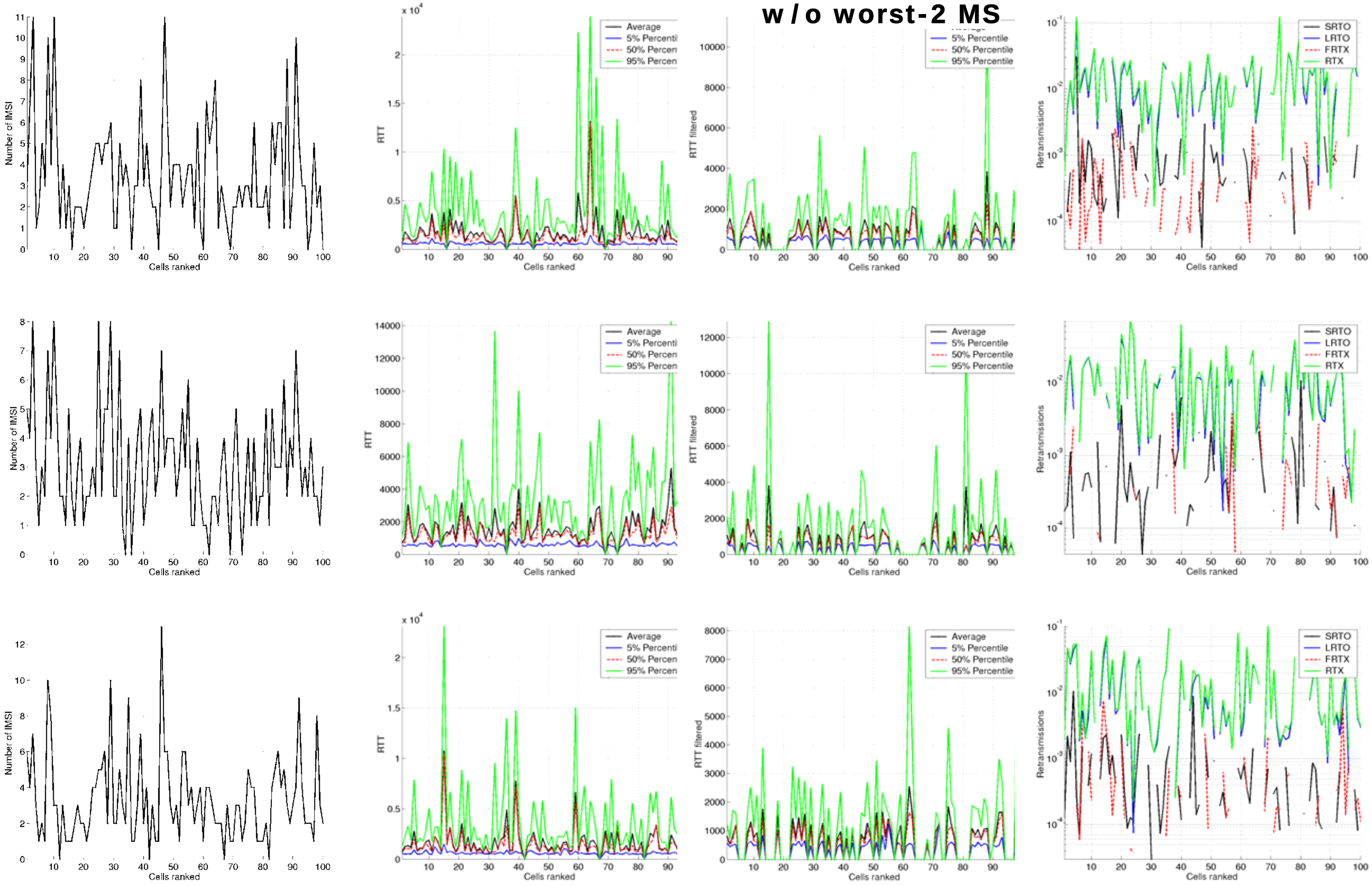
(per-cell measurements, 20^{00}-21^{00}h for 3 days, only „fixed“ traffic)

 # 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)

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