8. QoE and QoS Monitoring and data analyses

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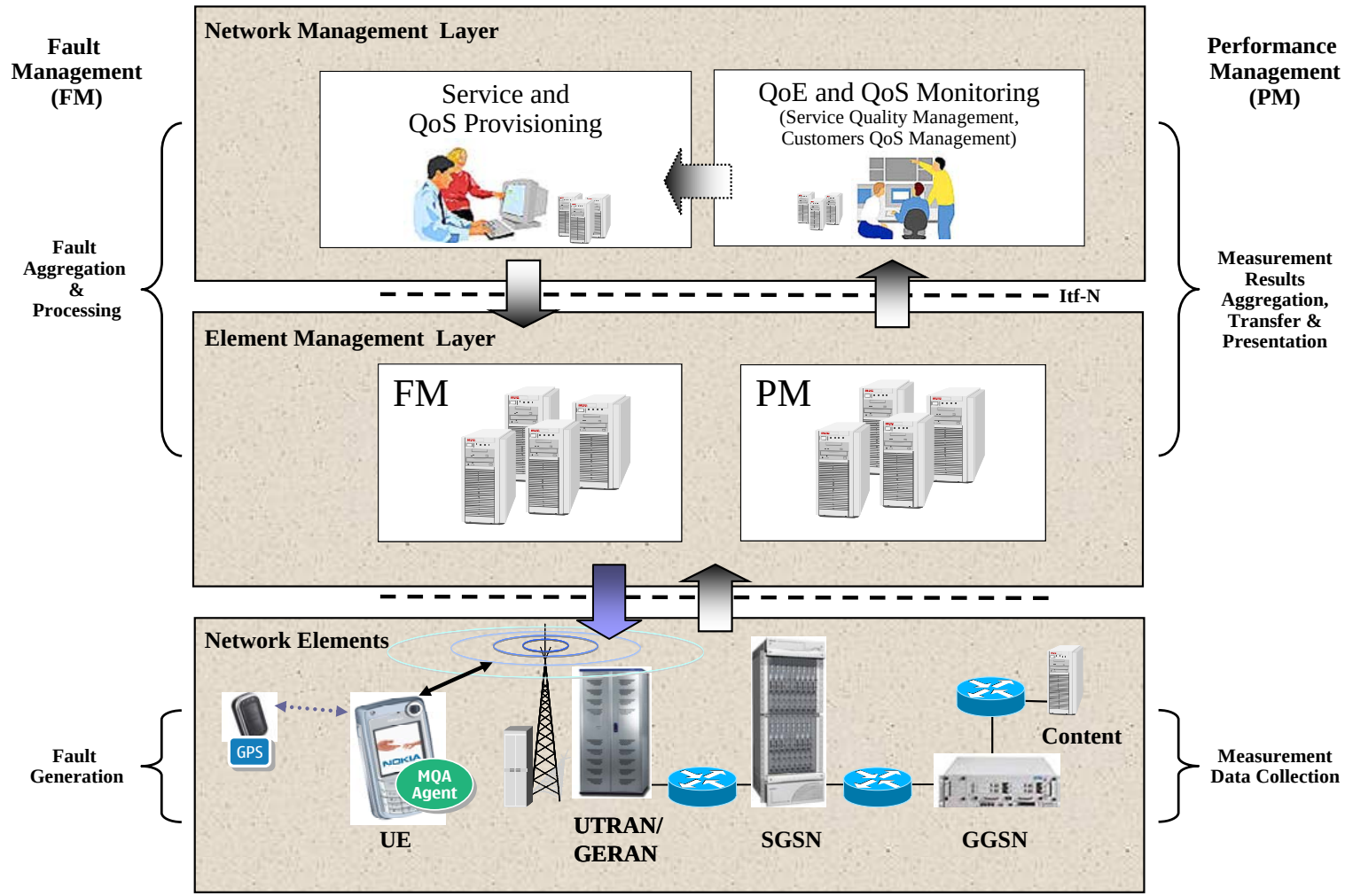
S-38.3215 Special Course on Networking Technology for Ph.D. students at TKK

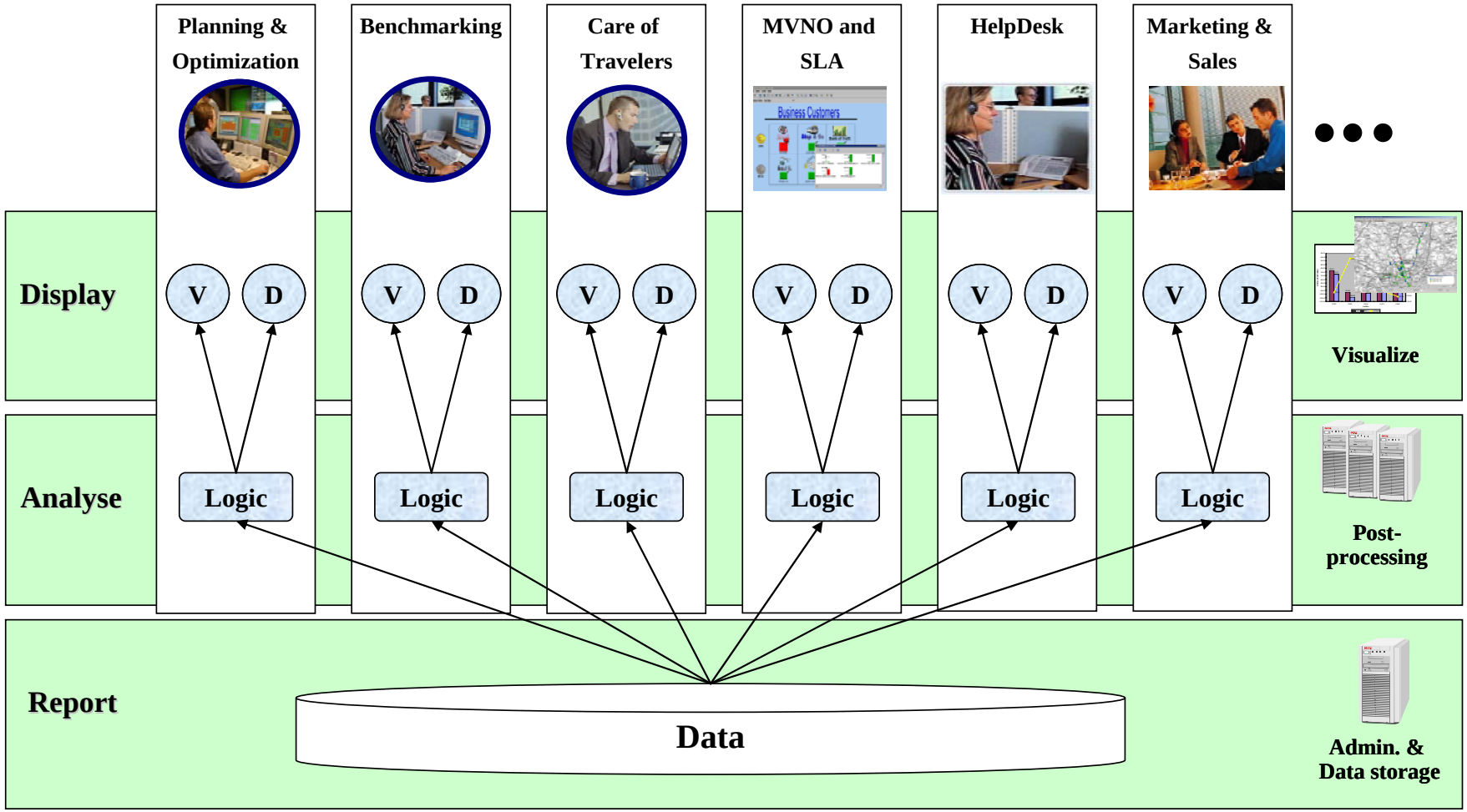
Outline

- QoE and QoS assurance concept
- QoE and QoS monitoring frameworks
- QoS Service Level Agreement
  - QoS SLA for IP transport and UMTS layers
- Confidence intervals on unknown parameters
- Statistical confidence on collected data
- QoE and QoS monitoring tools

Conceptual architecture (1/2)

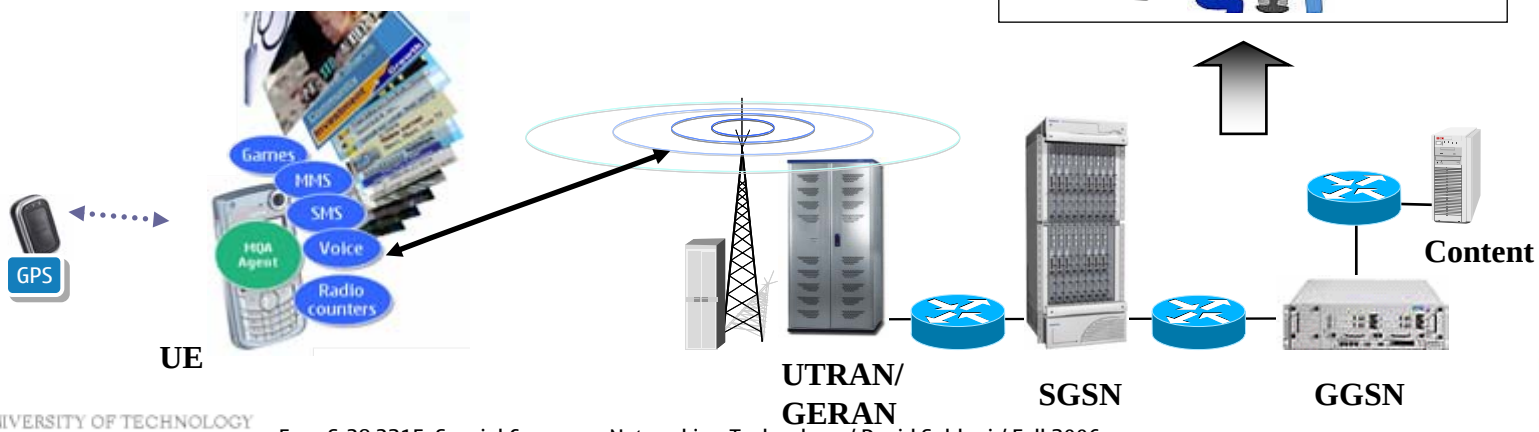


Conceptual architecture (2/2)



Approaches to measuring QoE

- QoE measurements using statistical samples
  - Key service weights and performance indicators
  - Statistical sample definition and MQA utilization
  - Overall QoE score (index) for each service and service mix
- NMS using QoS parameters
  - Collection of QoS performance
  - Mapping of QoS onto QoE



QoE Metrics: reliability and quality

- Accessibility & retainability

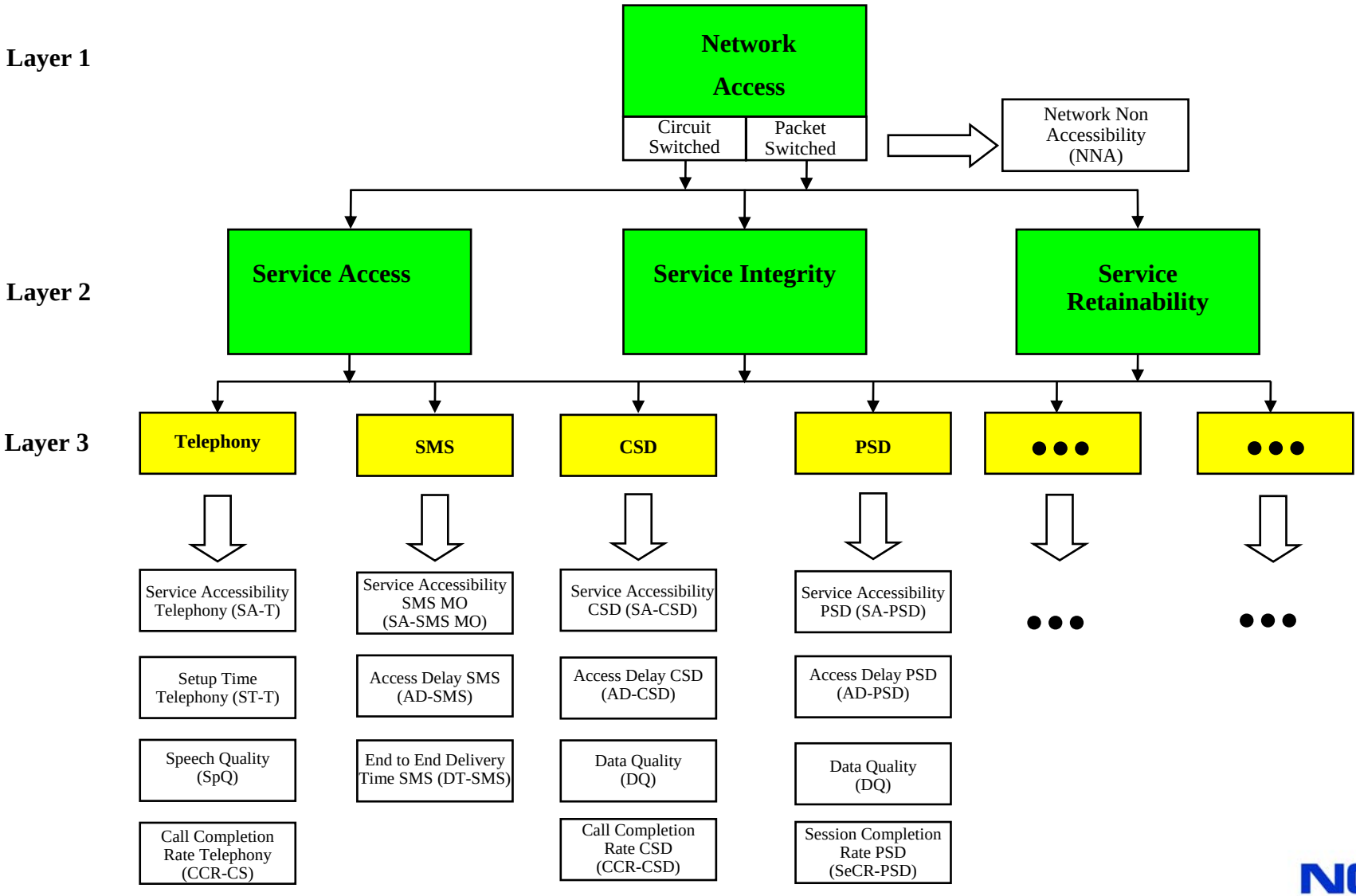
QoE KPI	Most Important Measurements
Service availability (Anywhere)	Ratio of territory under coverage to not under coverage (%)
Service accessibility (Anytime)	Ratio of refused connections or Ratio of PDP Context failed to establish in first attempt (%)
Service access time (Service setup time)	Average call or session set up time (s)
Continuity of service connection (Service retainability)	Service interruption ratio (%)

- Integrity

QoE KPI	Most important measurements
Quality of session	Service application layer packet loss ratio (%)
Bit rate	Average bearer bit rate achieved as ratio of bit rate demanded by application (%)
Bit rate variation	Bearer stability: Bit rate variation around negotiated bit rate (%)
Active session throughput	Average throughput towards mobile (kb/s)
System responsiveness	Average response time (s)
End to end delay	Average end to end delay (ms or s)
Delay variation	Jitter (%)

See also 3GPP SA4 work on “End-to-End Multimedia Services Performance Metrics”

ESTSI QoS parameters from end-user viewpoint



ITU Model for user-centric QoS categories

Error tolerant	**Conversational voice and video**	**Voice/video messaging**	**Streaming audio and video**	**Fax**
Error intolerant	**Command/control (e.g. Telnet, interactive games)**	**Transactions (e.g. E-commerce, WWW browsing, Email access)**	**Messaging, Downloads (e.g. FTP, still image)**	**Background (e.g. Usenet)**
	Interactive (delay << 1 s)	**Responsive (delay ~ 2 s)**	**Timely (delay ~10 s)**	**Non-critical (delay >>10 s)**

ITU-T performance targets for audio and video

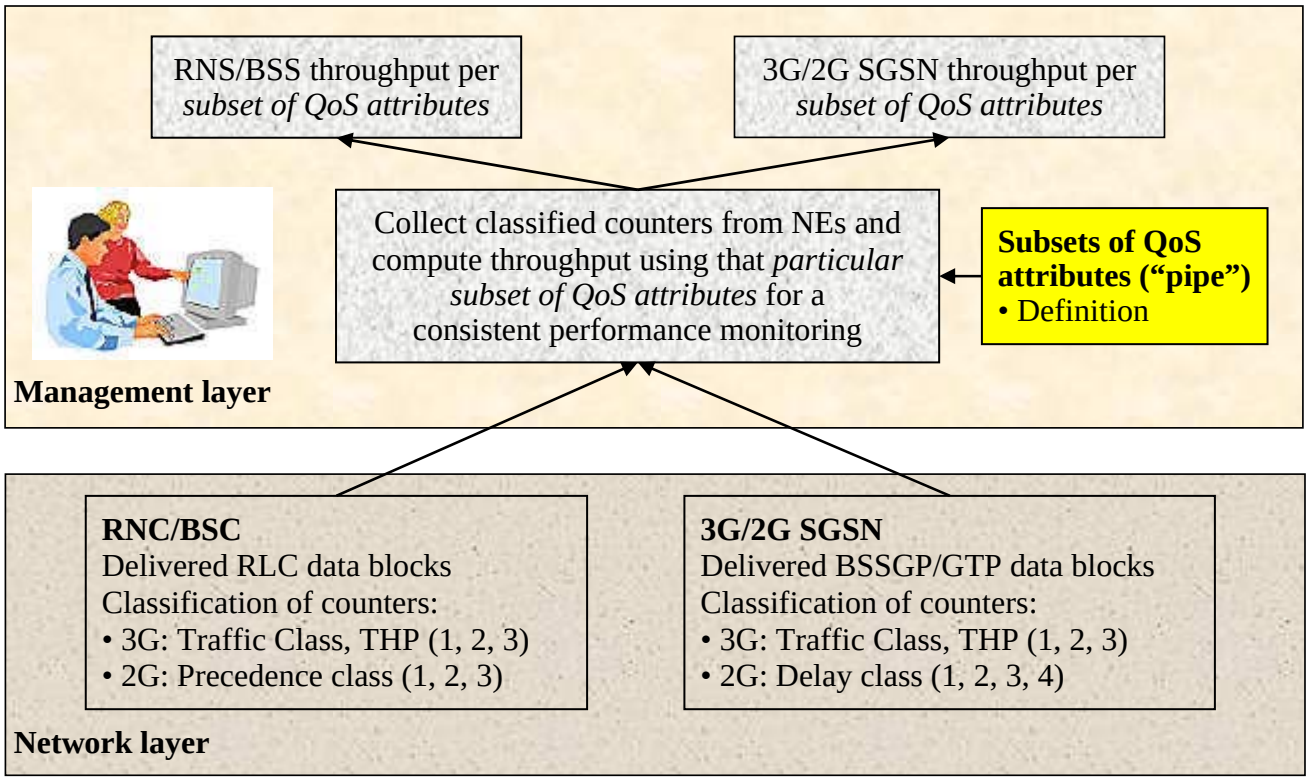
Medium	Service Application	Degree of symmetry	Typical data rates	Key performance parameters and target values			
				One-way delay	Delay variation	Information loss**	Other
Audio	Conversational voice e.g.telephony	Two-way	4-64 kb/s	< 150 ms preferred* < 400 ms limit*	< 1 ms	< 3% packet loss ratio (PLR)	-
Audio	Voice messaging	Primarily one-way	4-32 kb/s	< 1 s for playback < 2 s for record	< 1 ms	< 3% PLR	-
Audio	High quality streaming audio	Primarily one-way	16-128 kb/s ***	< 10 s	<< 1 ms	< 1% PLR	-
Video	Videophone	Two-way	16-384 kb/s	< 150 ms preferred**** < 400 ms limit		< 1% PLR	Lip-synch: < 80 ms
Video	Broadcast	One-way	16-384 kb/s	< 10 s		< 1% PLR	

* Assumes adequate echo control
** Exact values depend on specific codec, but assumes use of a packet loss concealment algorithm to minimise effect of packet loss
*** Quality is very dependent on codec type and bit-rate
**** These values are to be considered as long-term target values which may not be met by current technology

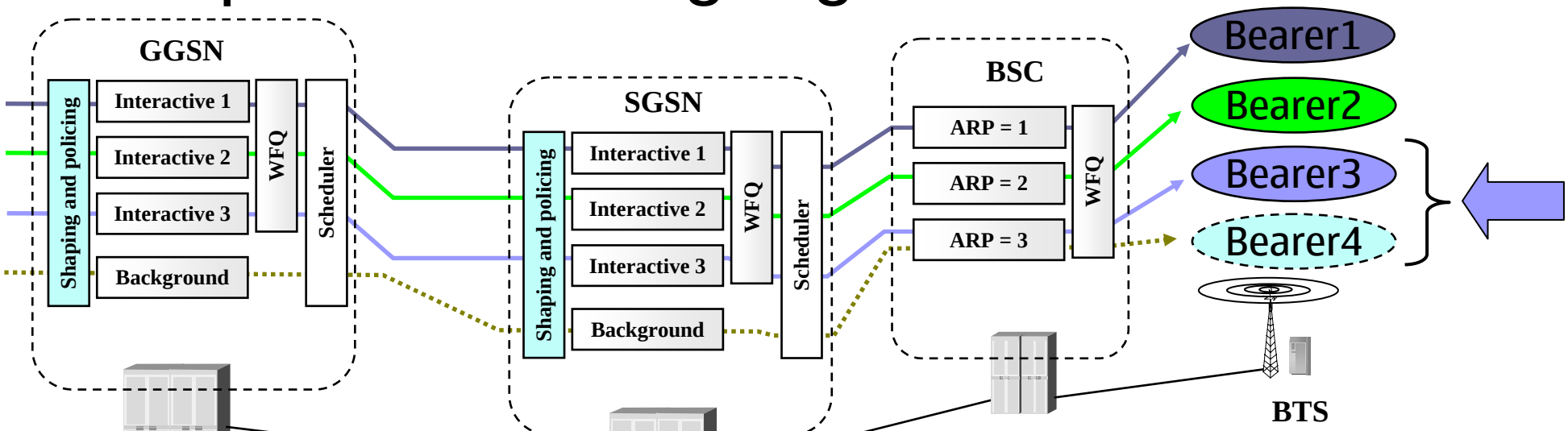
ITU-T performance targets for data

Medium	Service Application	Degree of symmetry	Typical amount of data	Key performance parameters and target values		
				One-way Delay	Delay variation	Information loss
Data	Web-browsing - HTML	Primarily one-way	~10 kB	Preferred < 2 s/page Acceptable < 4 s/page	N.A	Zero
Data	Bulk data transfer/retrieval	Primarily one-way	10 kB -10 MB	Preferred < 15 s Acceptable < 60 s	N.A	Zero
Data	Transaction services – high priority e.g. e-commerce, ATM	Two-way	< 10 kB	Preferred < 2 s Acceptable < 4 s	N.A	Zero
Data	Command/control	Two-way	~ 1 kB	< 250 ms	N.A	Zero
Data	Still image	One-way	< 100 kB	Preferred < 15 s Acceptable < 60 s	N.A	Zero
Data	Interactive games	Two-way	< 1 kB	< 200 ms	N.A	Zero
Data	Telnet	Two-way (asymmetric)	< 1 kB	< 200 ms	N.A	Zero
Data	E-mail (server access)	Primarily One-way	< 10 kB	Preferred < 2 s Acceptable < 4 s	N.A	Zero
Data	E-mail (server to server transfer)	Primarily one-way	< 10 kB	Can be several minutes	N.A	Zero
Data	Fax (“real-time”)	Primarily one-way	~ 10 kB	< 30 s/page	N.A	$<10^{-6}$ BER
Data	Fax (store & forward)	Primarily one-way	~ 10kB	Can be several minutes	N.A	$<10^{-6}$ BER
Data	Low priority transactions	Primarily one-way	< 10 kB	< 30 s	N.A	Zero
Data	Usenet	Primarily one-way	Can be 1 MB or more	Can be several minutes	N.A	Zero

QoS Monitoring framework



Example: counters/gauges classification



- IMSI for tracing subscribers
- PDP Type and address
- APN
- **QoS Profile Negotiated**
  - **Delay Class (1-4)**
  - Reliability Class (1-5)
  - **Peak Throughput Class (1-9)**
  - Precedence Class (1-3)
- Packet Flow Context
- Charging Characteristics
- Routing Area from SGSN IP address
- Micro flow
  - Source and destination addresses
  - Source and destination port numbers
  - Protocol type (ID)

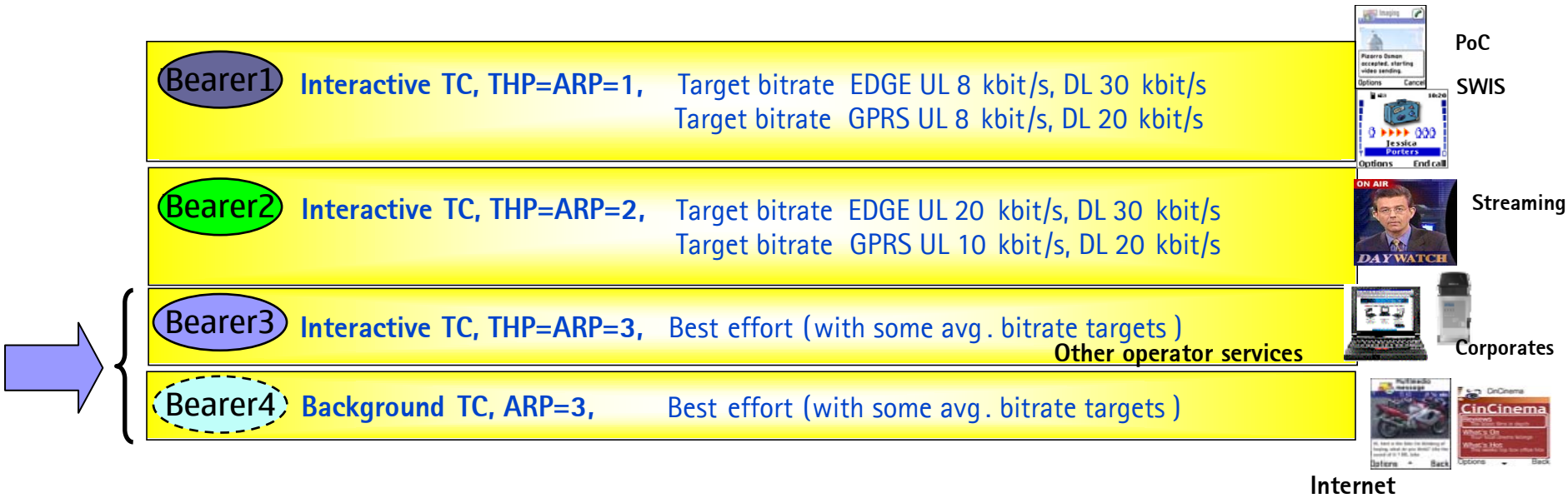
- IMSI or IMEI
- Radio Priority – UL
- PDP Type and address
- APN
- GGSN Address in Use
- **QoS Profile Negotiated**
  - **Delay Class (1-4)**
  - Reliability Class (1-5)
  - **Peak Throughput Class (1-9)**
  - Precedence Class (1-3)
- Packet Flow Context
- Aggregate BSS QoS Profile
- PDP Context Charging Characteristics
- Cell ID from BVCI
- Routing Area

- IMSI, e.g. if some terminal needs to be traced
- **BSS QoS Profile**
  - **Peak bit rate – DL and UL**
  - Type of BSSGP SDU (signalling or data) – DL
  - Type of LLC frame (ACK, SACK, or not) – DL
  - **Precedence Class (1,2,3)** – DL
  - Precedence used at radio access – UL
  - RLC/MAC transmission mode (AM, UM) – DL
- Modulation and Coding Schemes (MCS-CS)
- Cell from BVCI
- RA from SGSN IP address

UMTS-GPRS interworking
- R99 ARP = R97/98 Precedence Class
- R99 Interactive THP + BG = Delay Class

E2E Consistent treatment
- ARP1-3= THP1-3 = Precedent Class1-3 = Delay Class1-3
- Delay Class 4 = Background

Example: ‘pipes’ definition and mapping



- Note: If one ‘pipe’ carries more service applications, only the performance of the aggregate traffic can be assessed

Example: differentiate integrity monitoring

- **EDGE/GPRS Counters**
  - UL/DL correctly delivered RLC blocks
  - UL/DL related duration of TBF (***i***)
  - Measurement period (***S***)
  - Total number of collected TBFs (***N***)
- **Classification**
  - RLC transmission mode (AM, UM)
  - EGDE MCS 1-9 (***k***)
  - GPRS CS 1-4 (***k***)
  - Precedence Class ***p*** or ARP (1-3)
  - Cell identifier (Cell ID or BVCI)

- **Differentiated throughput analysis**
  - User throughput per 'pipe'

Total correctly delivered bits

Radio block size

$$t^{p} = \frac{\sum_{i=1}^{N} \sum_{k=CS-1}^{MCS-9} r_k B_i^{p,k}}{\sum_{i=1}^{N} d_i^{p}}$$

Correctly delivered RLC blocks

Total TBFs related duration

TBF *i* duration

  - Cell throughput per 'pipe'

Total correctly delivered bits

$$t_{cell}^{p} = \frac{\sum_{i=1}^{N} \sum_{k=CS-1}^{MCS-9} r_k B_i^{p,k}}{S}$$

Measurement period

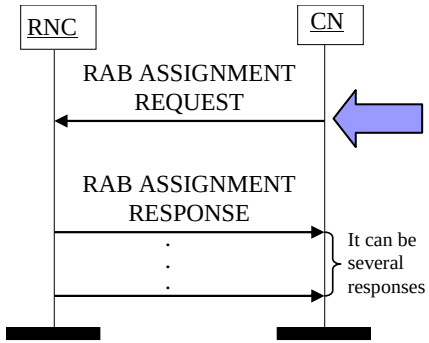
2G: BSS

Example: differentiated reliability monitoring

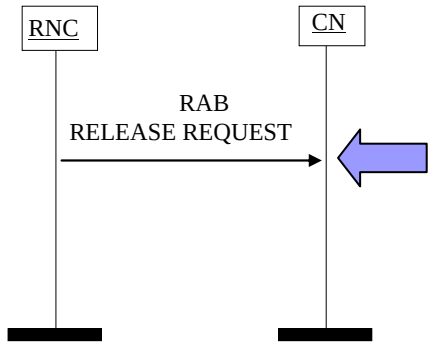
- RAB management

$$RAB.SuccRatio.m = \frac{\sum RAB.Rel.UE.m}{\sum RAB.AttEstab.m}$$

***m* = 'pipe'**



a)

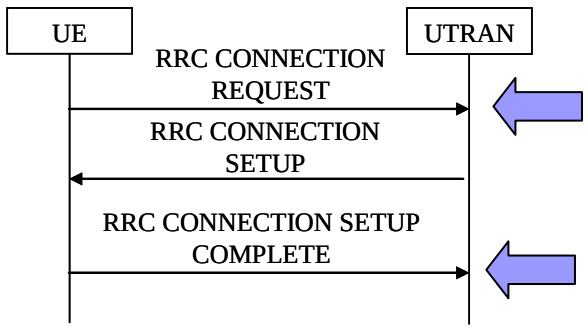


b)

- Signaling connection management

$$RRC.SetupAccessCompleteRatio.Cause = \frac{\sum RRC.SuccConnEstab.Cause}{\sum RRC.AttConnEstab.Cause}$$

reason



3G: RAN

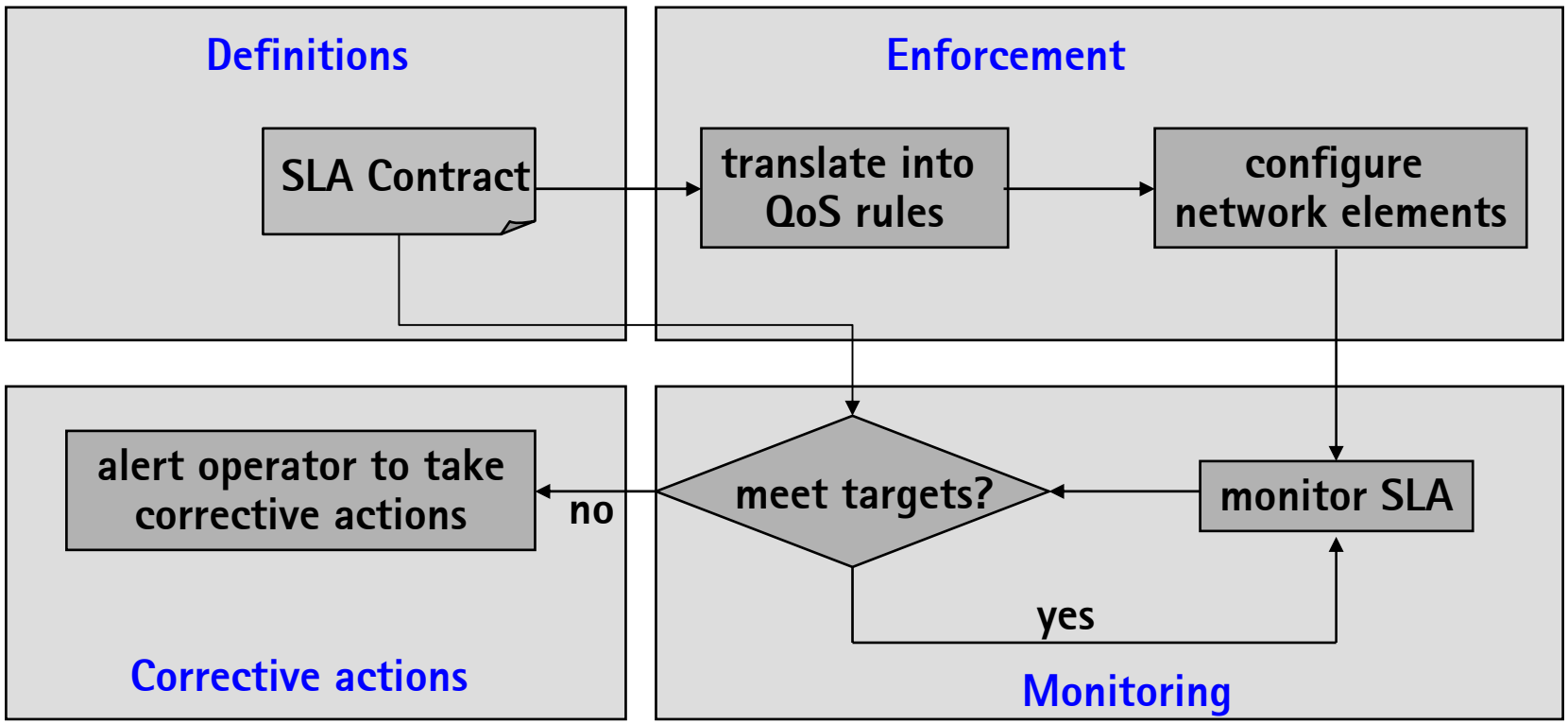
QoS Service Level Agreement

- Definition
- IP layer SLA QoS management
- UMTS layer SLA QoS management

Service Level Agreement

- A service level agreement (SLA) is a **formal negotiated contract** between two parties, e.g., an enterprise customer and a mobile operator
- The purpose of an SLA is to create a **common understanding about services, priorities, responsibilities** between the two parties
- Mobile operator will likely see the popularity of SLA increases as more enterprises sign up for mobile services, and as more multimedia services are being provisioned over mobile networks

SLA QoS management framework



Contents of a generic SLA QoS contract

- **Network scope**
  - Where the SLA QoS applies
- **Service schedule**
  - The period during which the SLA applies
- ***Customer traffic flow* identifiers**
  - Parameters to uniquely identify a customer traffic flow
- **Performance parameters and their target values**
  - To be experienced by customer traffic flows
  - Directly tied to customer traffic flow identifiers

    Customer traffic flow identifier #1: performance targets #1

    Customer traffic flow identifier #2: performance targets #2

Contents of a generic SLA QoS contract

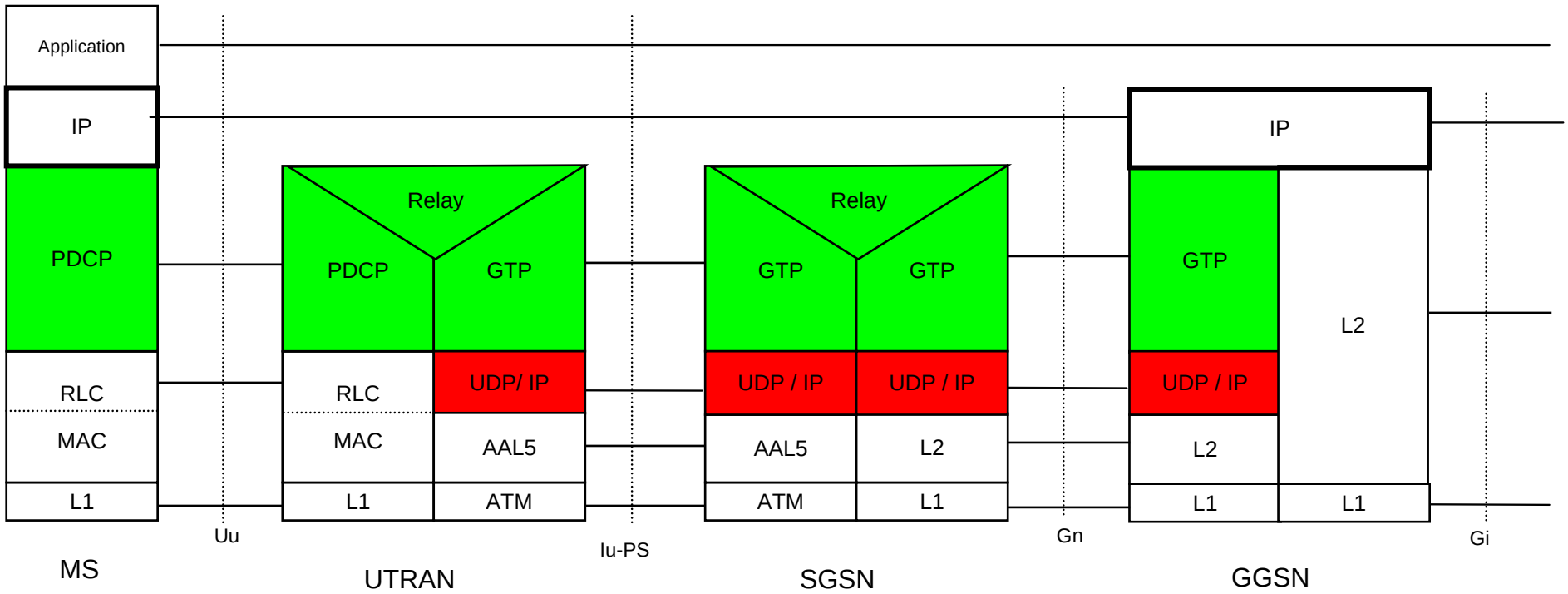
- **Traffic profiles**
  - Traffic characteristics for each type of customer traffic flow
- **Non-conformance actions**
  - Treatment for the traffic flows that exceed their profile, e.g, drop or delay
- **Action of SLA violation**
  - Penalties on the operator if QoS SLA contract is violated, e.g., reduction of service fees paid by customer
- **SLA monitoring and reporting mechanisms**
  - How an operator makes monitoring results available to customers

Monitoring Technologies

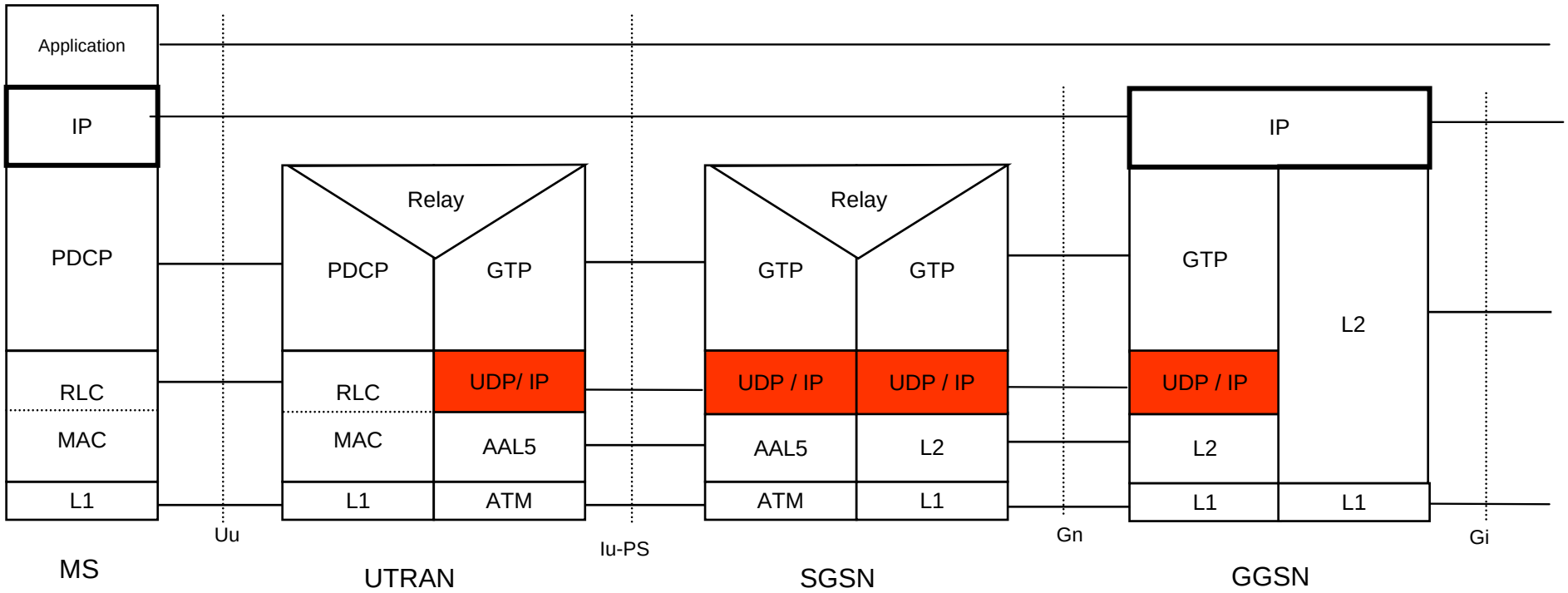
- SLA QoS management solution must decide on the monitoring technologies
- **Active vs. passive measurements**
  - **Active**: injects test traffic into the network to measure network performance
  - **Passive**: derive network performance by monitoring existing user traffic
- **External probe vs. embedded agent**
  - **External**: using specialized monitoring device, e.g. Mobile QoS Agent
  - **Embedded**: monitoring component embedded inside network elements, e.g. Service assurance tool on routers

SLA for Different Layers

- IP transport layer QoS and UMTS layer QoS SLAs
  (Note that there are two IP layers: user IP and transport IP.)

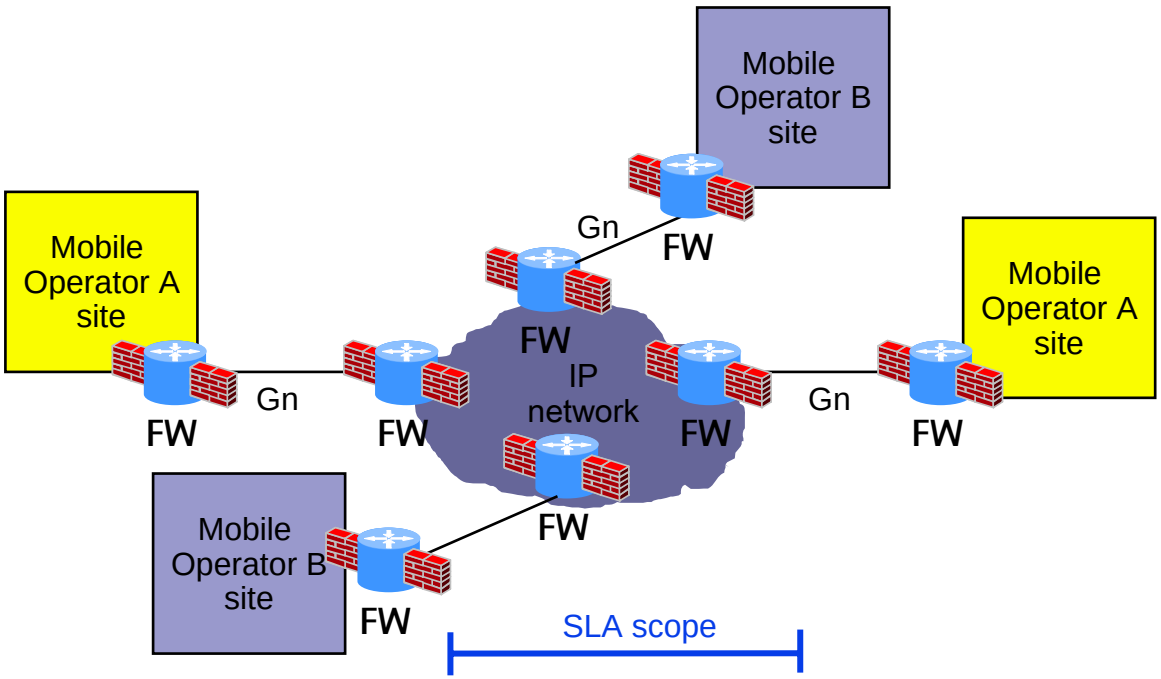


SLA for IP Transport Layer



Use Case: SLA between mobile and IP operators

- The IP network that connects mobile sites are shared by multiple operators
- IP network operator signs SLA contracts with mobile operators



FW: Firewall

Customer traffic flow identifiers

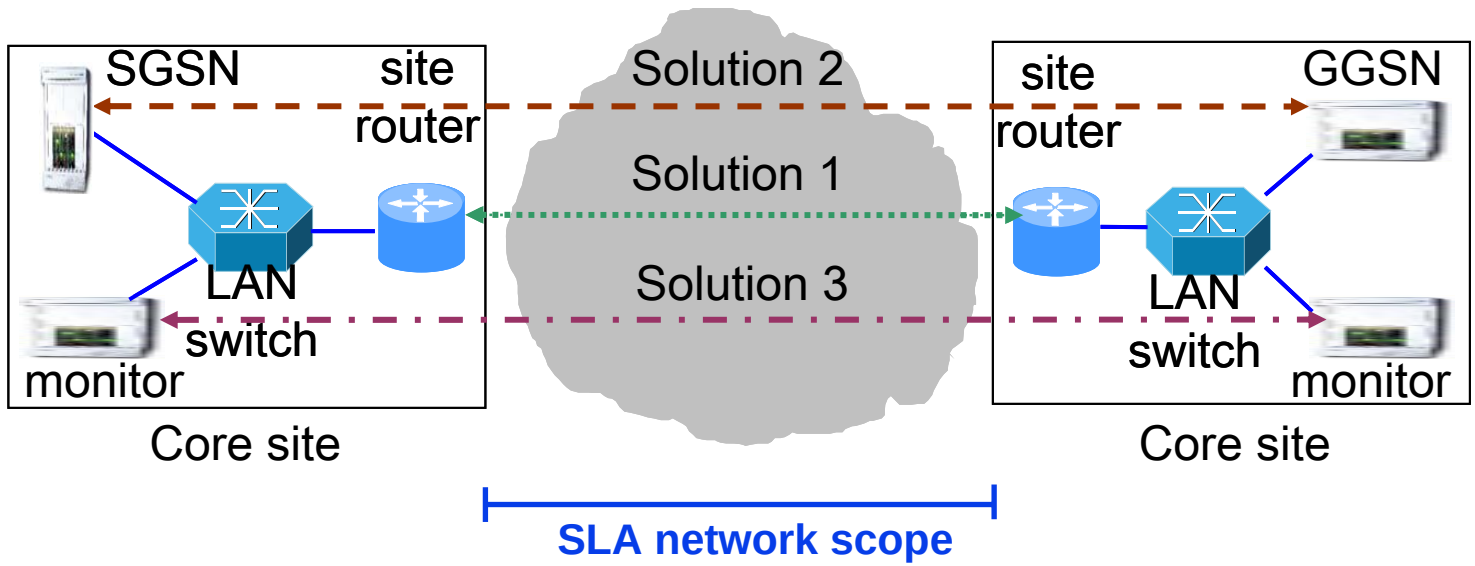
- Combination of the following fields in IP packets:
  - Source IP Address
  - Destination IP address
  - Source port number
  - Destination Port number
  - Protocol
  - DSCP
  - Flow ID (IPv6)
  - Other higher layer fields
- A field can be a wild card – anything matches

Performance parameters

Performance parameter	Expedited Forwarding	Assured Forwarding	Best Effort
Delay (one way or round trip)	X		
Delay jitter	X		
Packet loss ratio	X	X	
Throughput	X	X	
Bearer availability	X	X	X

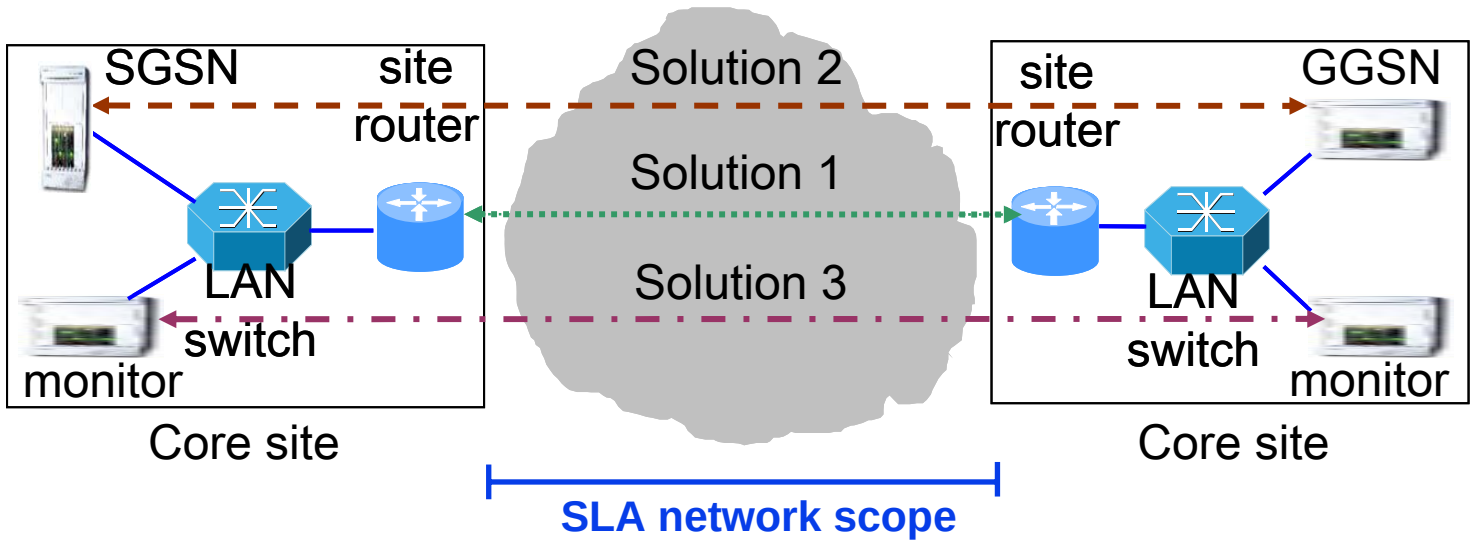
IP Transport layer SLA QoS monitoring

- Throughput may be monitored passively at interfaces
- Packet delay, jitter, loss and bearer availability may be monitored through active measurement



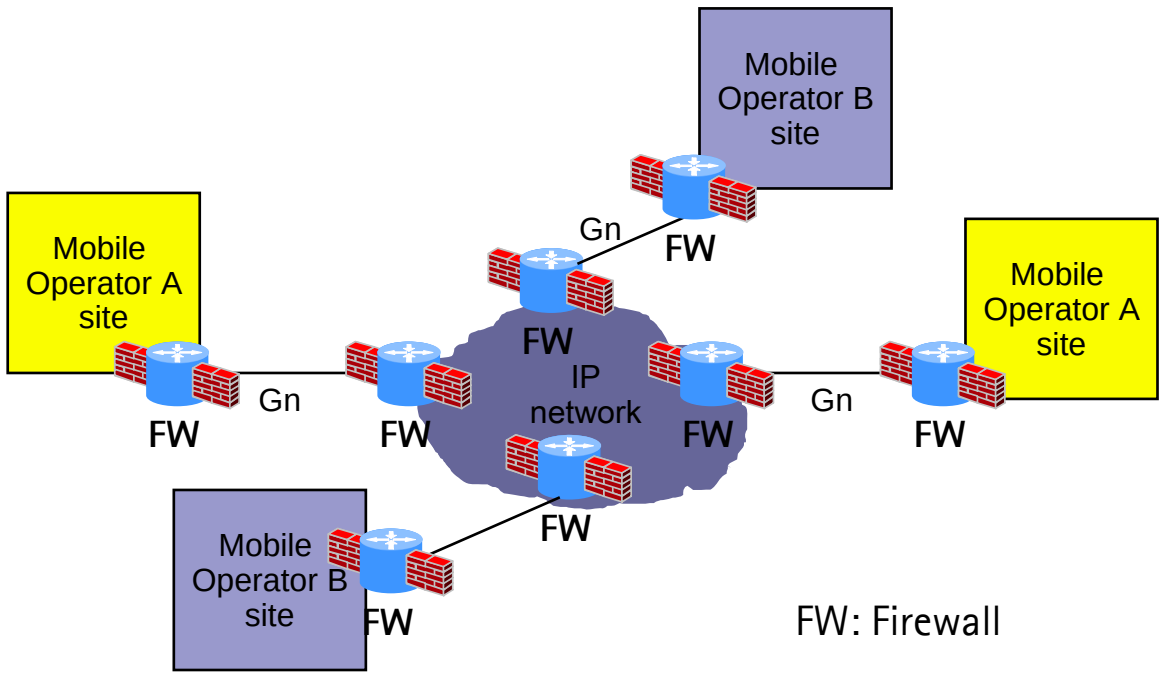
IP Transport layer SLA QoS management

- **Three possible active measurement solutions**
  - # 1, using Cisco router SAA tool for active monitoring
  - # 2, implementing active monitoring functions on GSN
  - # 3, installing dedicated active monitoring devices

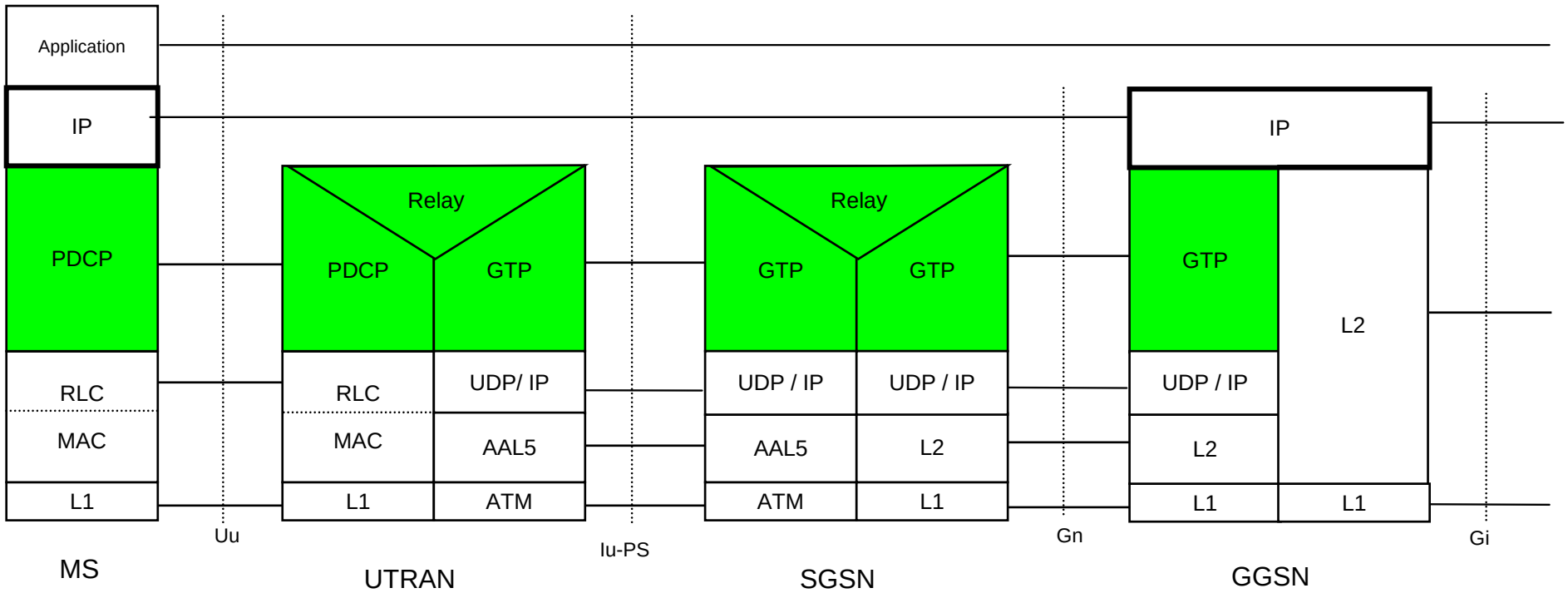


Back to the Use Case

- The IP network that connects mobile sites are shared by multiple operators
- IP network operator signs SLA contracts with mobile operators
- SLA QoS contents
  - throughput, delay, jitter and loss for each Diffserv class between mobile sites
  - IP backbone availability
- PLMN can measure and verify the SLA by itself

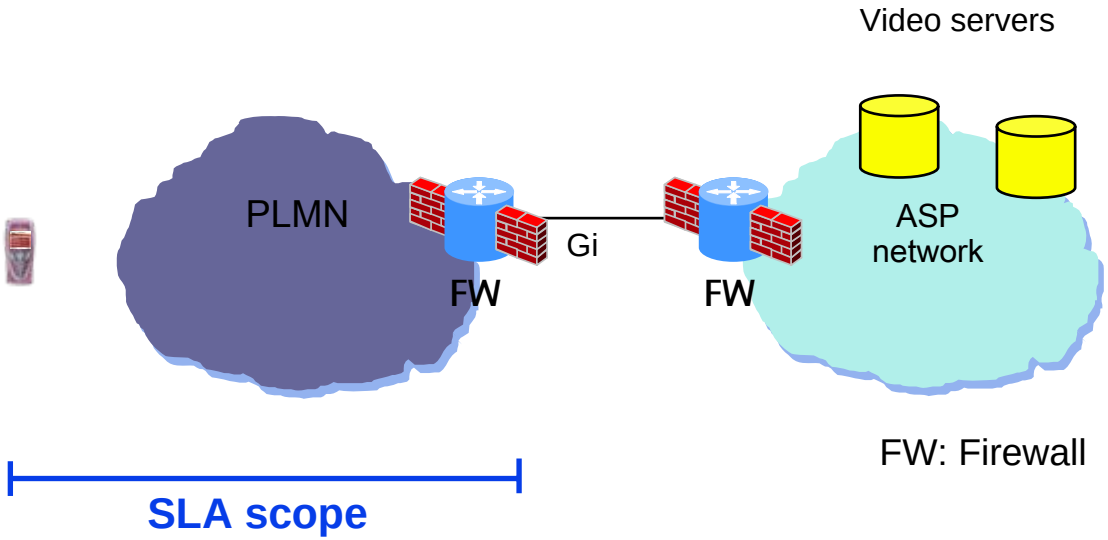


SLA for UMTS Layer



Use Case – SLA between Mobile Network Operator and Application Service Provider

- Mobile network operator (MNO) signs SLA contract with an application service provider (ASP)



Customer traffic flow Identifiers

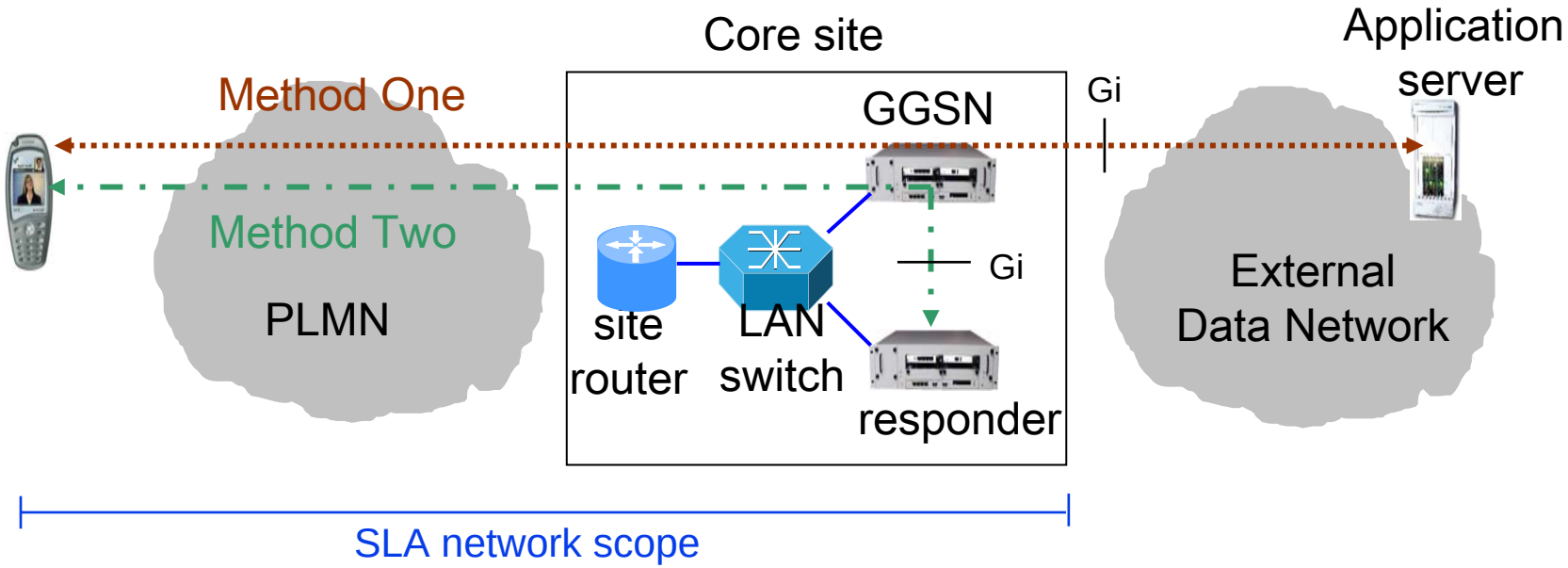
- Combination of the following parameters
  - IMSI
  - MSISDN
  - Traffic class, THP, ARP, MBR, GBR
  - Access point name
  - Source and destination IP addresses
  - Protocol, port numbers
  - Other higher layer fields
- A field can be a wild card – anything matches

Performance parameters

Performance parameter	Conversational	Streaming	Interactive	Background
Delay (one way or round-trip)	X	X		
Delay jitter	X	X		
Packet loss ratio	X	X	X	
Throughput	X	X		
Packet error ratio	X	X	X	X
Service response time	X	X	X	
Packet reordering	X	X	X	X
PDP-context session blocking ratio	X	X	X	X
PDP-context session availability	X	X	X	X
PDP-context session retain ability	X	X	X	X
PDP-context session access time	X	X	X	X

UMTS layer SLA QoS monitoring solution

- Monitor by sampling per PDP-context session performance for throughput, delay, packet loss, error ratio, service response time and traffic profile parameters by GGSN and mobile devices
  - Method one: Passively monitor application traffic
  - Method two: Active monitoring by installing responders at core sites

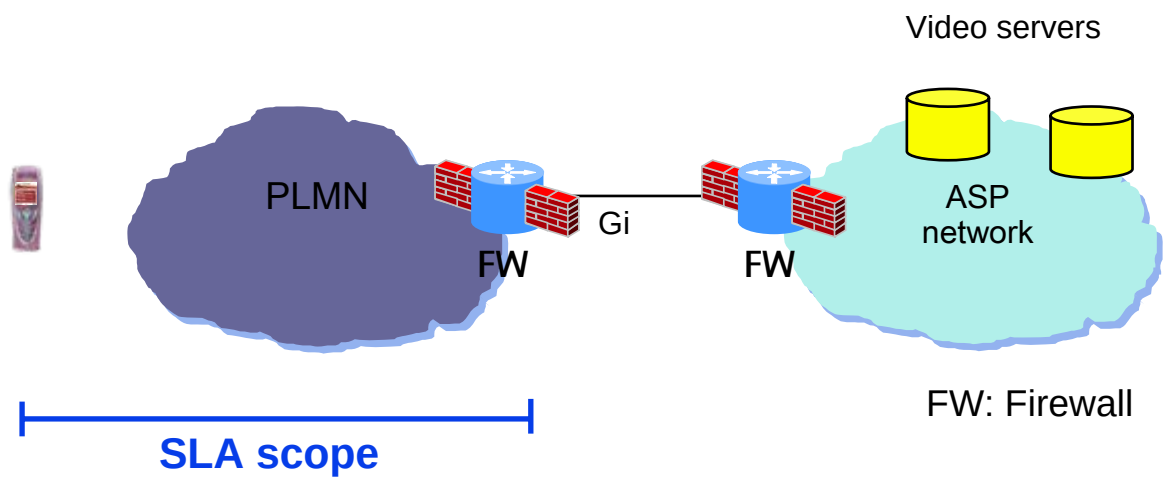


UMTS layer SLA QoS management solution

- Aggregate throughput and traffic profile at Gi are monitored by GGSN
- PDP-context Session Blocking Ratio, PDP-context Session Availability, PDP-context Session Retain ability, PDP-context Session Access Time are monitored by
  - SGSN; or
  - mobile terminal

Back to the Use Case

- **Mobile operator signs SLA contract with the ASP**
- **SLA QoS contains for each service and subscriber group**
  - **User IP packet throughput, delay, jitter, loss, error ratio and traffic profile**
  - **Total uplink and downlink IP packet throughput and traffic profiles at Gi interface**
  - **PDP-context session performance**
- **Mobile operator should measure the SLA parameters and make the measurement available to the ASP**



Confidence interval on unknown parameter

- **Smooth away effects of extremes or 'outliers'**
  - Median instead of Mean (Average)
  - Inter Quartile Range (IQR), i.e. 75^{th} – 25^{th} quartile, instead of Variance or Standard Deviation
- **Calculation of C.I. on an unknown parameter**
  - Find the function that approximate best the **distribution** of simulated or measured data, e.g. using Chi-Square test
  - A percentage confidence interval on a parameter, $100*(1-\alpha)$, correlates with the reliability (or repeatability) of performance results, e.g.
    - Confidence interval on a *proportion* (using the binomial distribution)
    - Confidence interval on the *mean* of a normal distribution where the variance is unknown (using the t-distribution)

Statistical confidence on measured data

- Statistical confidence on a **proportion *p***
  - Find the sample size ***n*** to be **100*(1-α) percent** confident that the relative error $\Delta p/p$ is less than a specified value ***E***
- Statistical confidence on a ***measurement of time***
  - Find the sample size ***n*** to be **100*(1-α) percent** confident that the deviation from the real mean value is less than a specified threshold ***a*** for a given ***expected mean*** and ***standard deviation*** value
- ***Local average power*** of a mobile radio signal
  - Find the ***sampling period*** for the power measurements of the radio signal to be **90% confident** that the deviation from the real local mean of the signal strength is less than **1dB**

Examples

1) Relationship between the accuracy of the estimator of a proportion and the number of calls to be observed

Confidence Interval	95	%		
p	5	%	Proportion (e.g. **expected unsuccessful call ratio**)	
$\Delta p/p$	10	%	Error (**required accuracy** for p)	
Measurement interval	3600	s	A	
Mean arrival rate per UE	600	s	B	
α	0.0500		C	
$\sigma(\alpha)^2$	3.8415		D	$(1-\alpha/2)*100$ percentile of $N(0,1)$
$(1-p)/p$	19.0000		E	
$(\Delta p/p)^2$	0.0100		F	
n	**7299**		G = D*E/F	**Required number of call attempts**
UE	**1217**		H = G/A*B	**Needed Mobile Agents**

2) Method of calculating the number of observations required for measurements of time

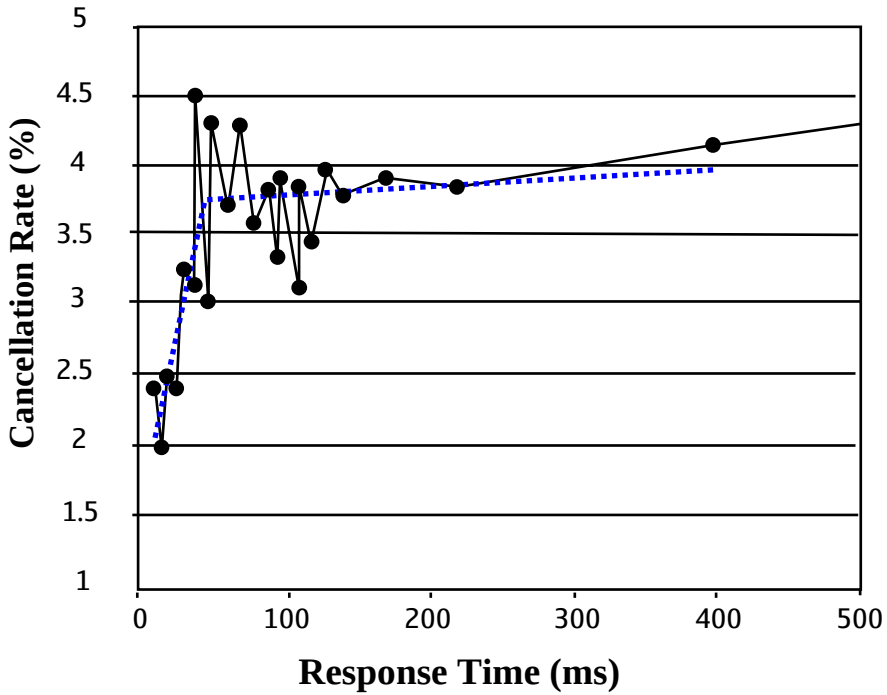
Confidence Interval	95	%		
s	0.2	s	Expected **standard deviation** of the call setup time (calculated from former measures)	
x	3.5	s	Expected **mean value** of the call setup time (calculated from former measures)	
a	2	%	Relative accuracy	
Measurement interval	3600	s	A	
Mean arrival rate per UE	600	s	B	
α	0.0500		C	
$\sigma(\alpha)^2$	3.8415		D	
a^2	0.0004		E	
$(s/x)^2$	0.0033		F	
n	**32**		G = D/E*F	**Required number of observations**
UE	**6**		H = G/A*B	**Needed Mobile Agents**

3) Estimate of local average power of a mobile radio signal (90% confidence, 1 dB accuracy)

v	3	km/h	A	UE speed
f	2150	MHz	B	Transmission frequency
λ	0.14	m	C	
Minimal Sampling Period	134	ms	D = 1000*0.8*C*3.6/A	(W. C. Y. Lee)

Mapping of QoE onto QoS performance

- Objective Indicators vs. Subjective Measurements



QoS KPIs	QoE subjective scale				
	Excellent	*Very good*	*Average*	*Fair*	*Poor*
End-to-end delay (median)	≤ 2s	≤ 4s	≤ 8s	≤ 15s	≥15s
Packet loss ratio	≤ 0%	≤ 0.1%	≤ 1%	≤ 5%	≥ 5%
Mean Throughput	≥ 200kb/s	≥ 120kb/s	≥ 60kb/s	≥ 20kb/s	≤ 20kb/s

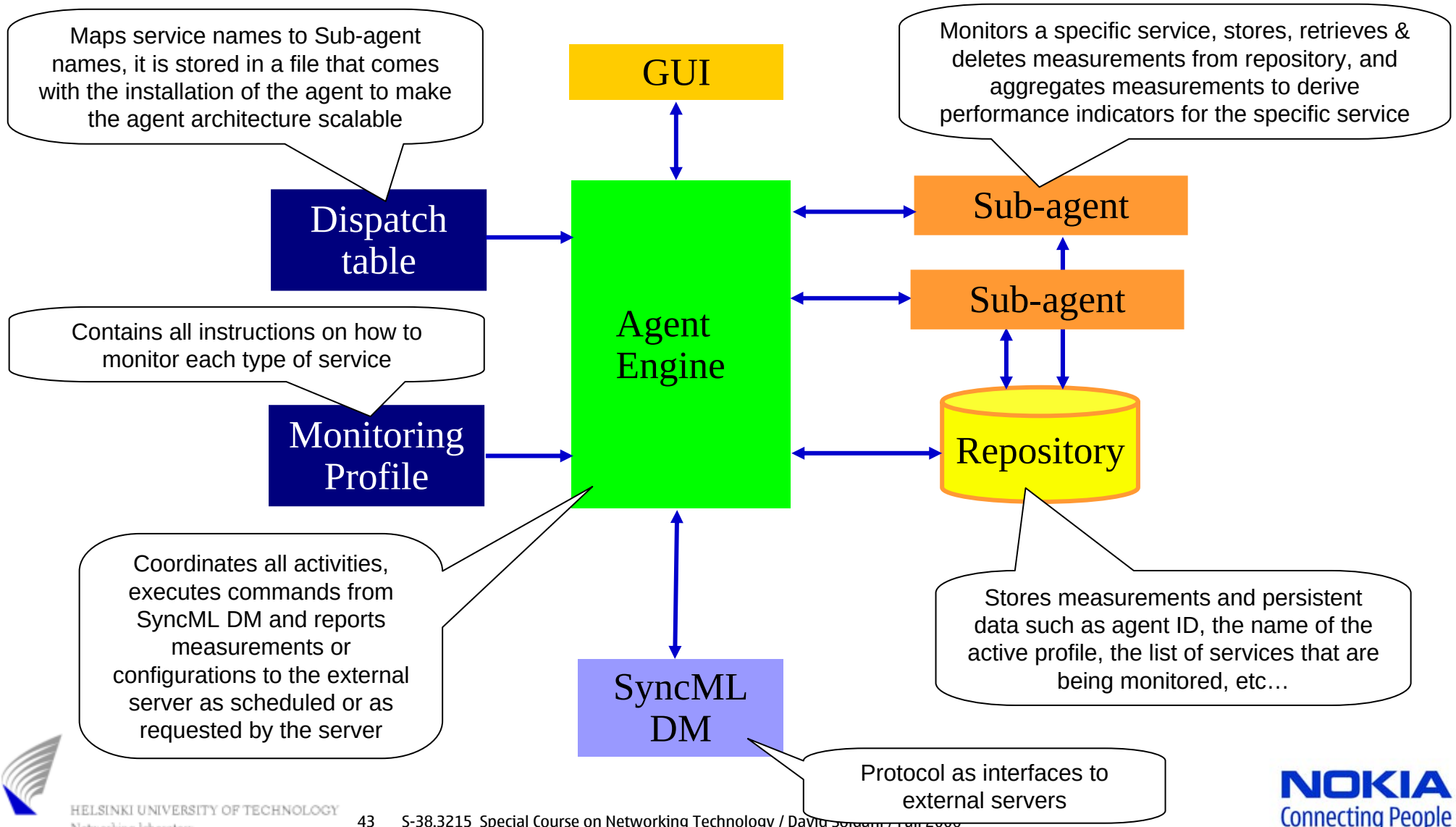
QoE monitoring tools

- Application layer tools
  - E.g. Ping, FTP, HTTP browsing, MMS, SIP, WAP, etc…
- Field measurement tools
  - Radio measurements + application layer performance
- Protocol analyzers
  - Protocol stack performance analysis at any interface
- Mobile QoS agents
  - L1-L7 measurements, position and location
  - Active and passive measurements

Mobile Quality Agent (MQA) functions

- **Measuring** mobile multimedia service quality, radio parameters, and producing **and reporting performance** statistics to central management servers
- **Active probing** and/or **passive monitoring**, which turns thousands of commercial mobile phones into (secure and non intrusive) service quality probing stations
- A **central management server** derives KPIs out of the reports from QoS agents, and manages QoS agents, i.e. dynamically dispatches, installs, and activates or deactivates them

What is a Mobile Quality Agent (MQA)?



Use cases: why an MQA?

- **Network planning** and **optimization**, monitoring multimedia services quality and radio interface performance where subscribers exactly are, **reducing the needs of traditional drive or walk tests**
- **Benchmarking** with the competition or collecting quality of foreign networks for a fact based comparison
- **Taking care of particular customers segments**, such as corporate or VIP users (e.g. business travelers) and keeping **service level agreement** promise
- **Selling what the operator can deliver**, **understanding customers better (helpdesk)** by collecting data of different categories, and **launching only successful services**
- **Solution for emerging Mobile Virtual Network Operators** to monitor service quality and check whether the mobile operators meet the service level agreements

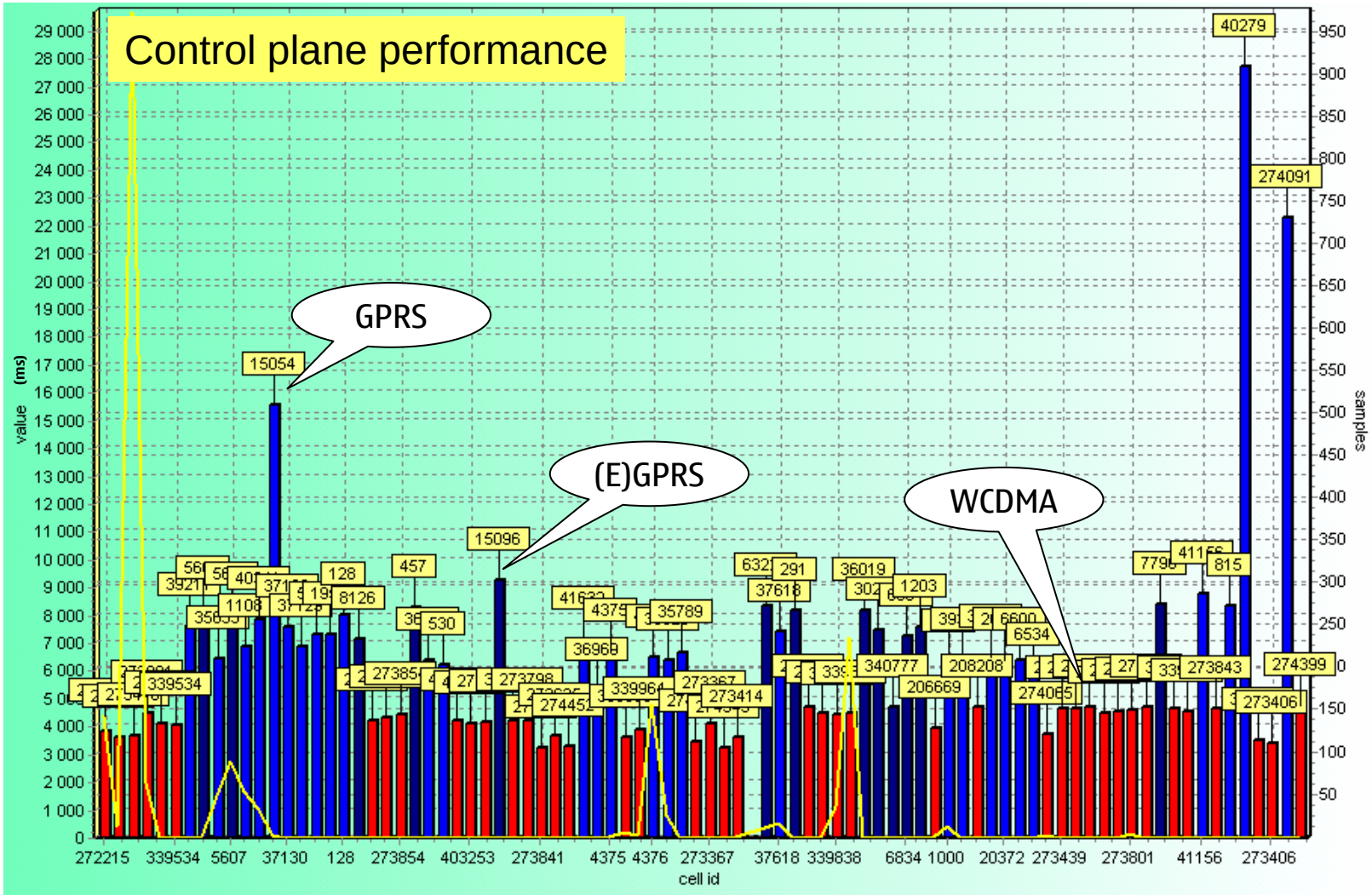
Experimental validation by means of prototyping

- **Active measurements and one Sub-agent for Web browsing + Radio counters**
- **Sampling period of 1-2 s; session period of 10 minutes; reporting period of 30 minutes**
- **Download of two Web pages at a fixed and changing the handset position**
  - 92.26 kB (54.63 kB text, 37.63 kB for 15 images)
  - 500 kB (text only)
- **Bearer service counters**
  - Number of successful PDP context activations and activation times
  - Service application setup time (request for a web page is sent - http response header is received)
  - Function time (http response header received - page completely downloaded)
  - Number of successful browsing attempts; total number of data received (in bytes)
  - Total number of packets received
  - Average throughput for the download during the session
- **Bearer types**
  - GPRS, EGPRS, and UMTS
- **3G radio measurements**
  - RSCP and Ec/N0 of 4 best cells (A, M and D); Active set size; UE Tx power max and received SIR
- **2G radio measurements**
  - Rx Level; DL and UL BLER; CS1-4/MCS1-9 coding scheme classes; and timing advance
- **GPS position and network location**

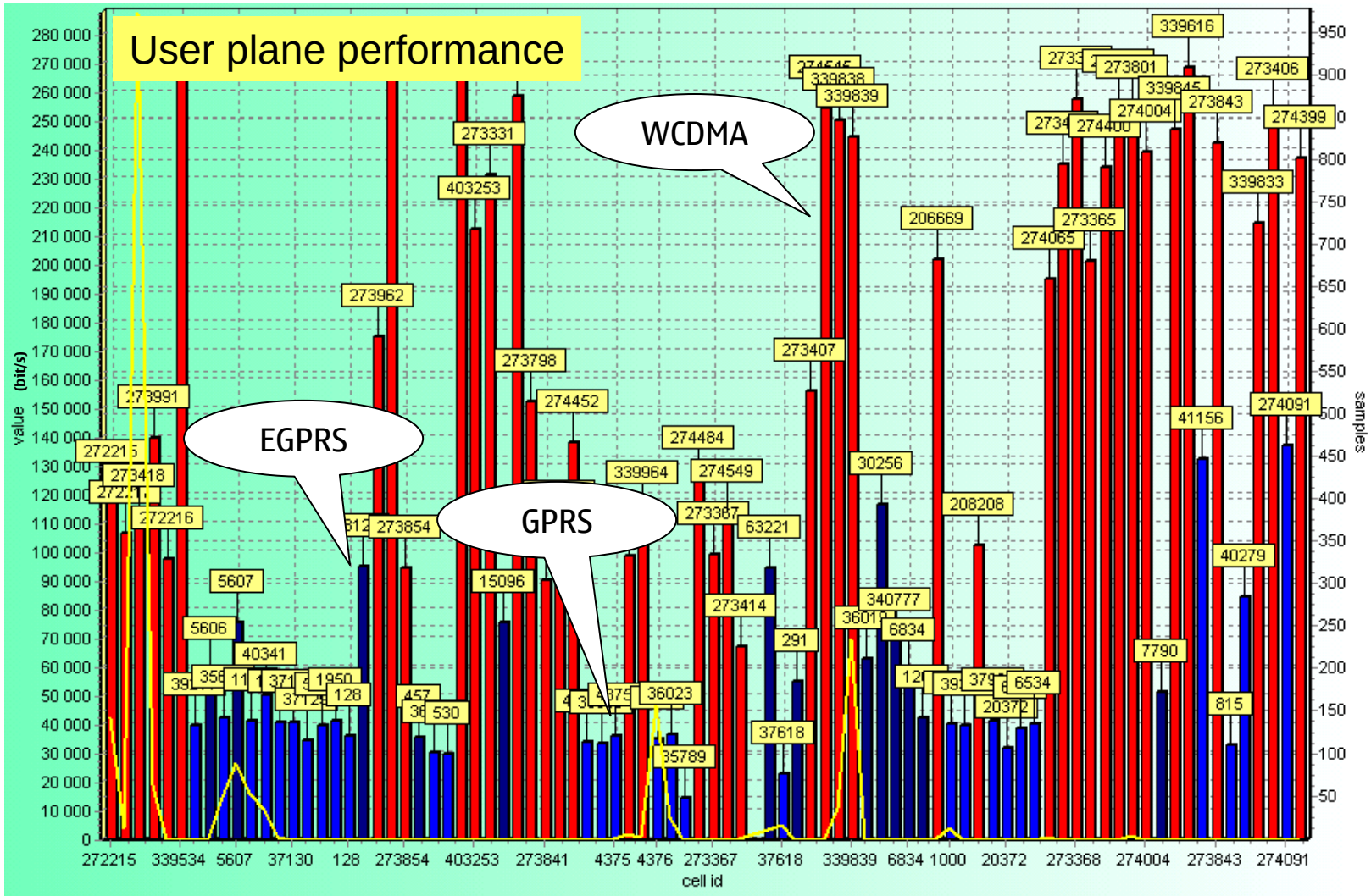
Measurement setup

- Real 3GSM network
- 10 handsets (Nokia 6630, 6680) connected to a GPS via Bluetooth

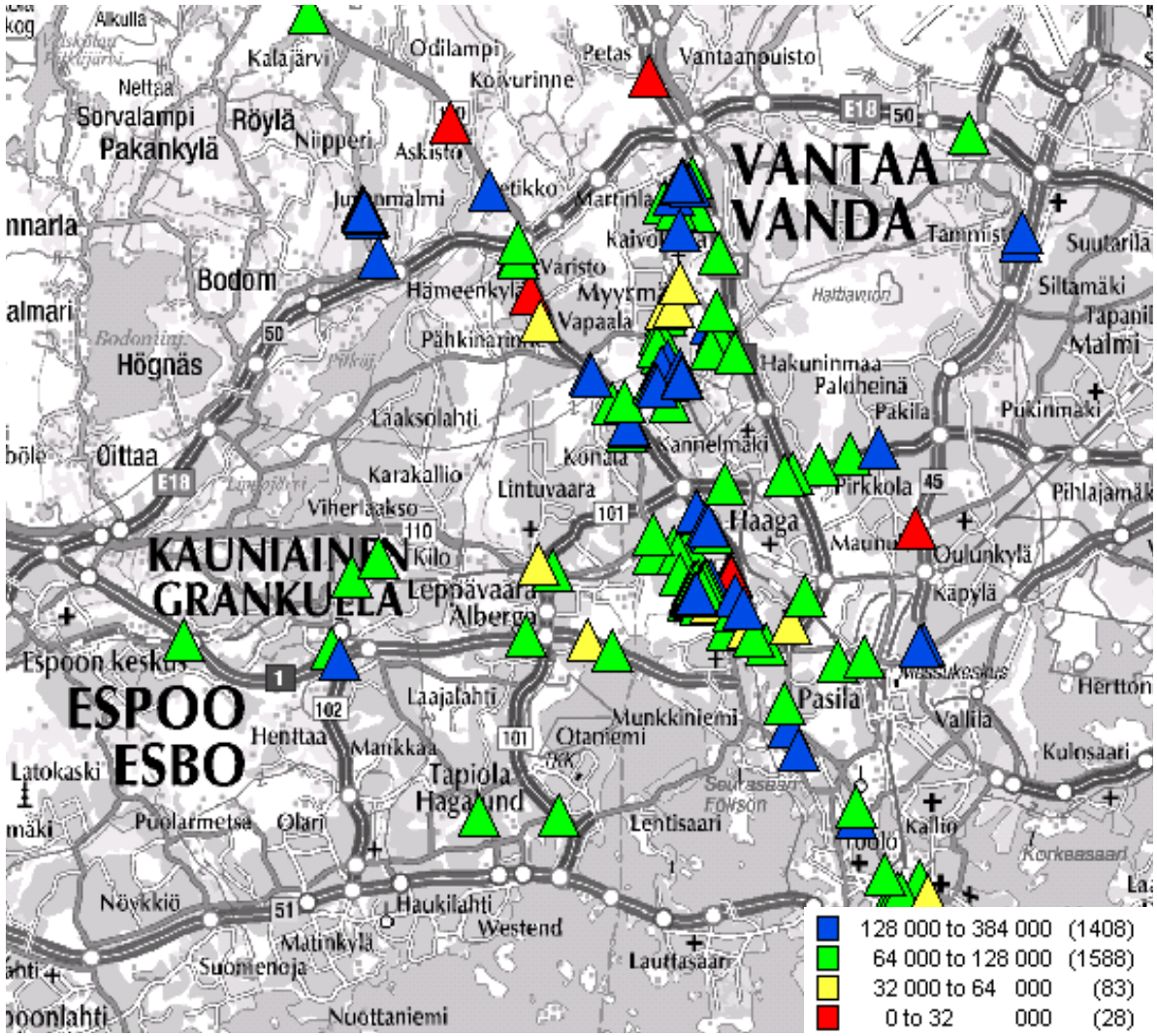
GPRS attach & PDP context setup time



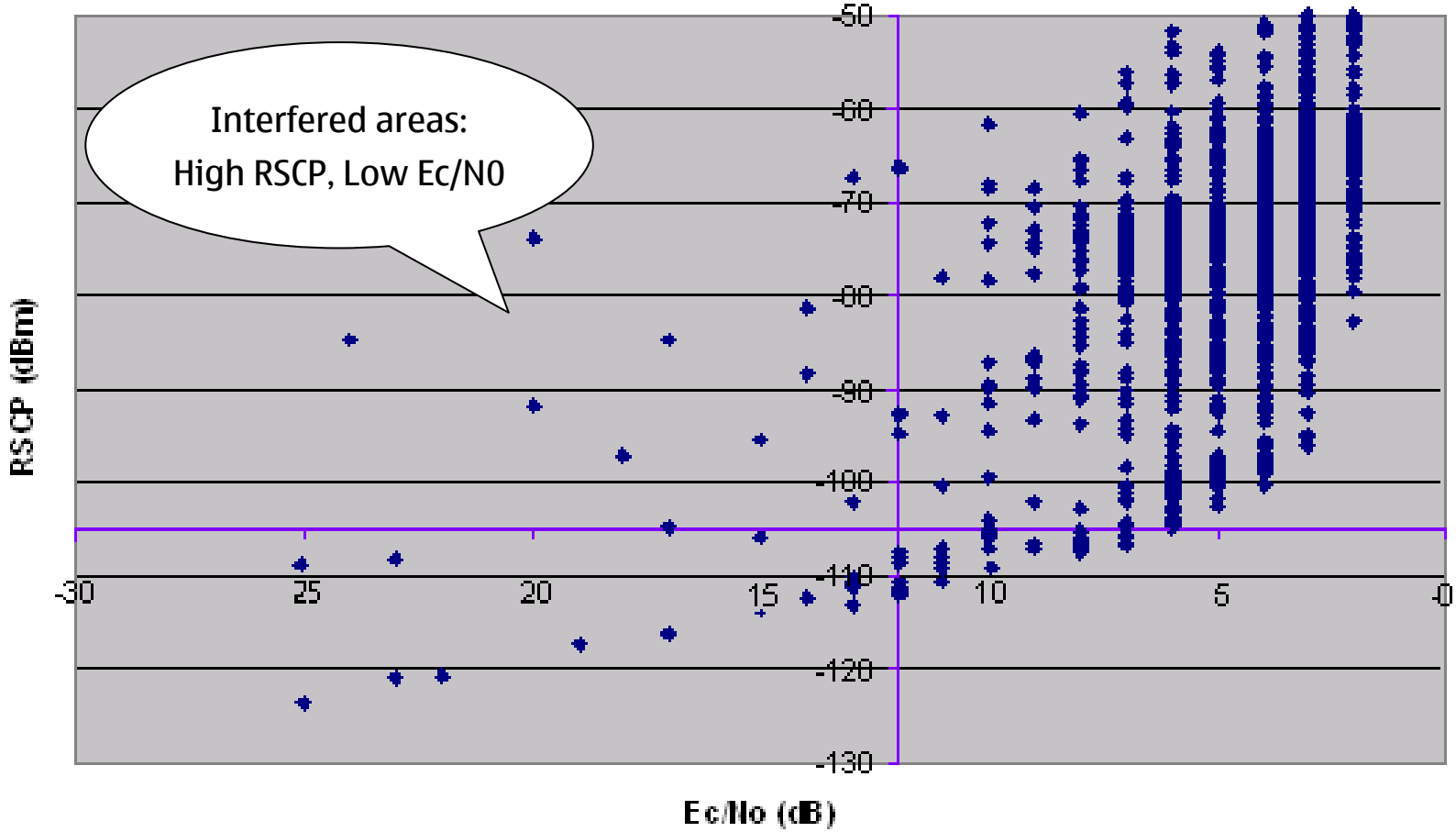
Average throughput per session



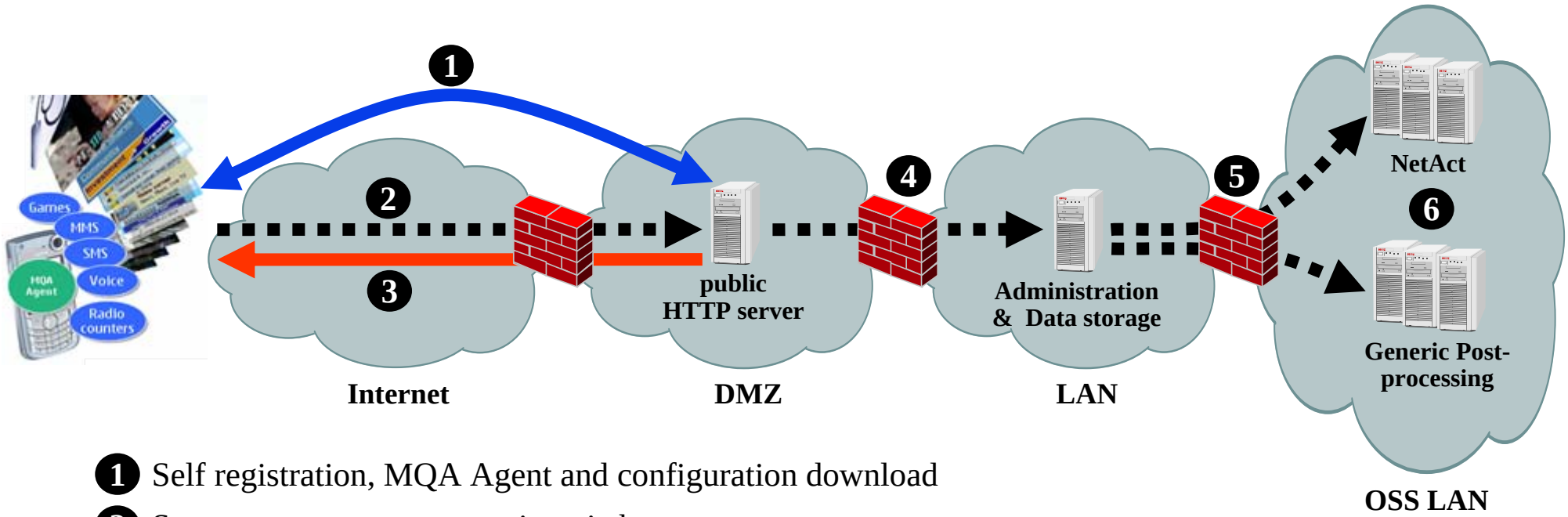
WCDMA average throughput per session



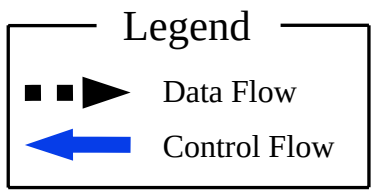
Interference analysis per cell



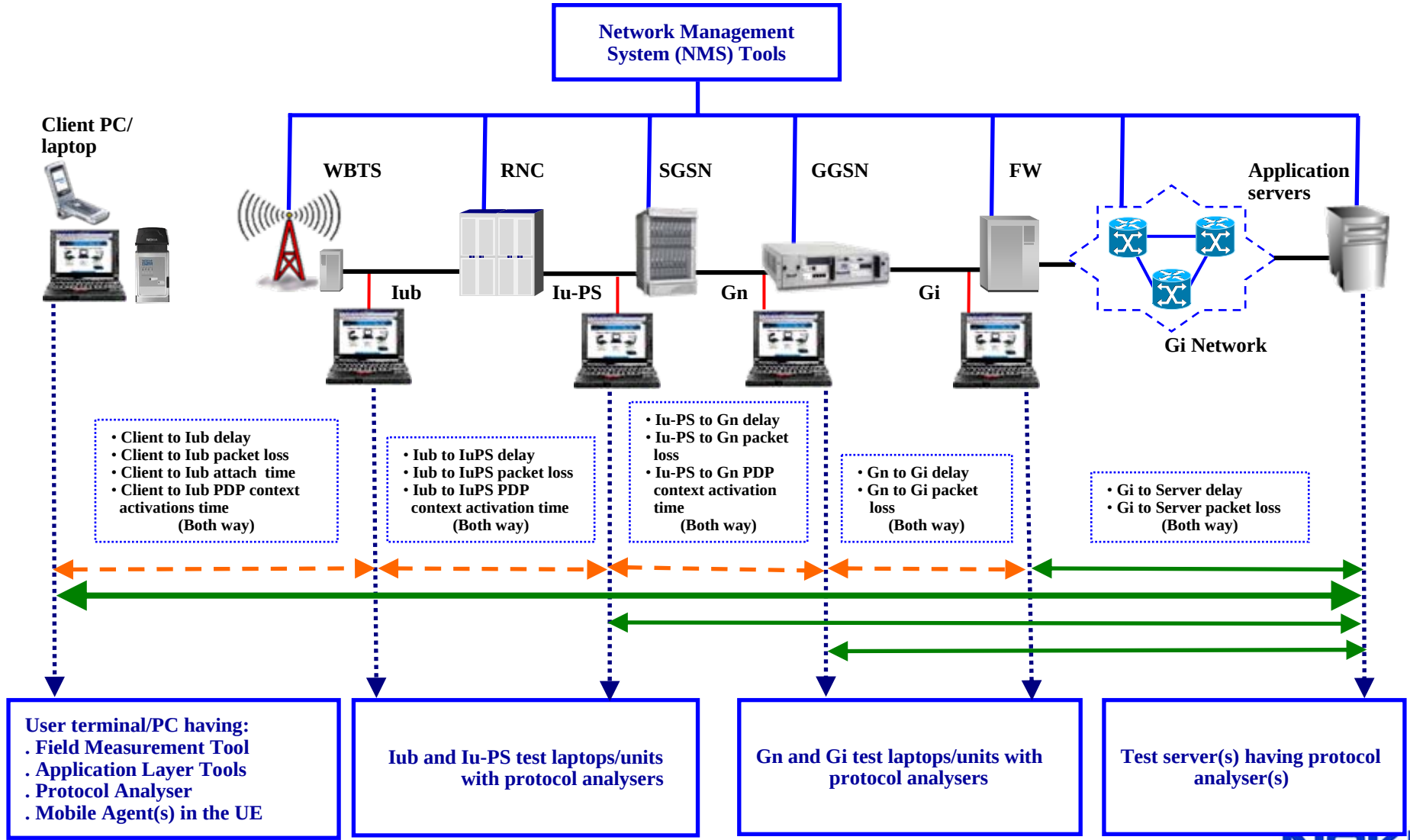
Example: Nokia Mobile Quality Analyzer



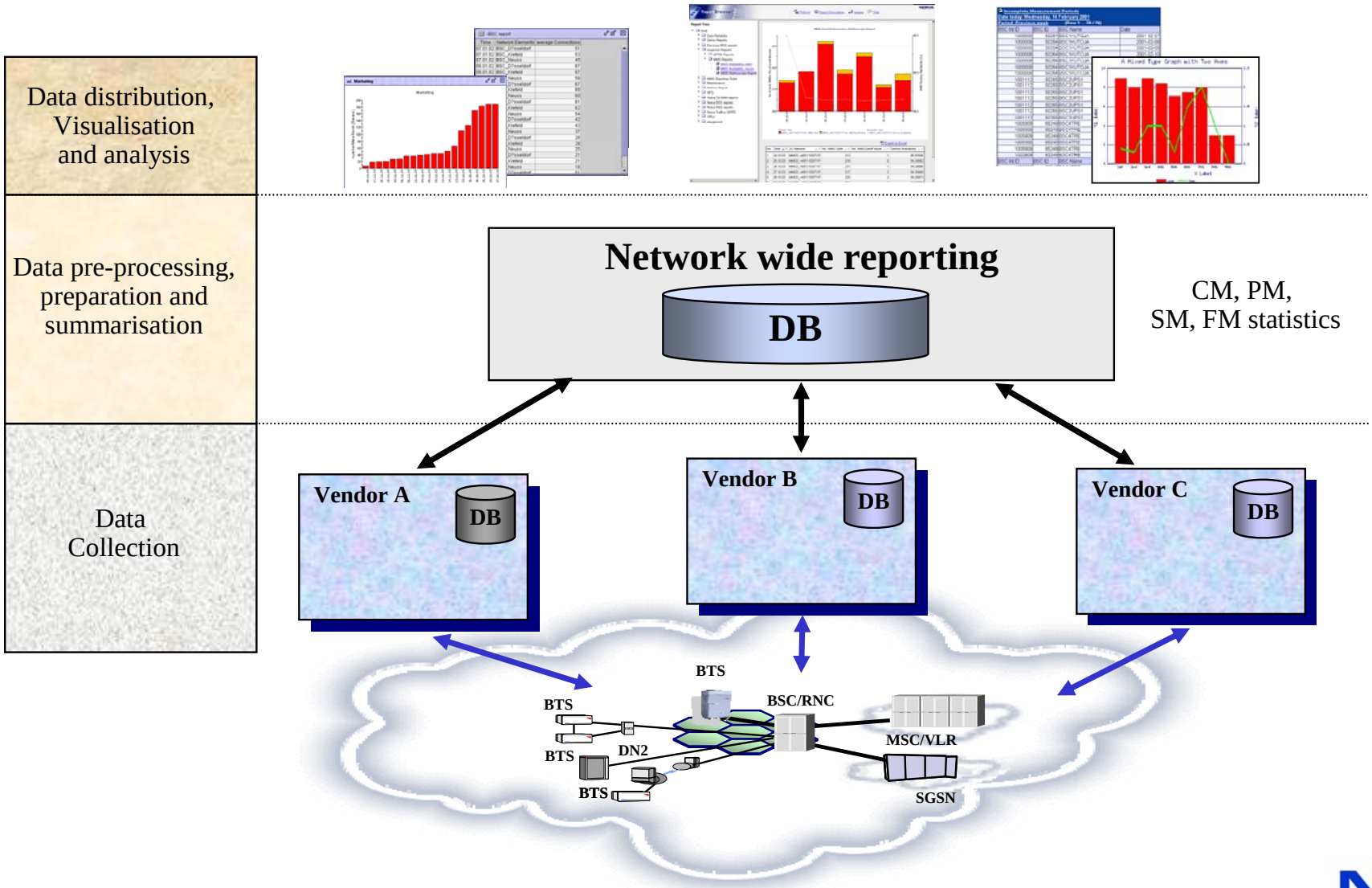
1. Self registration, MQA Agent and configuration download
2. Secure measurement reporting via https post
3. Download and update MQA configuration if available
4. Measurement collection in database
5. Measurement forward to Reporting System (e.g. Nokia NetAct™, 3rd party, …)
6. Data Analyze and Report generation



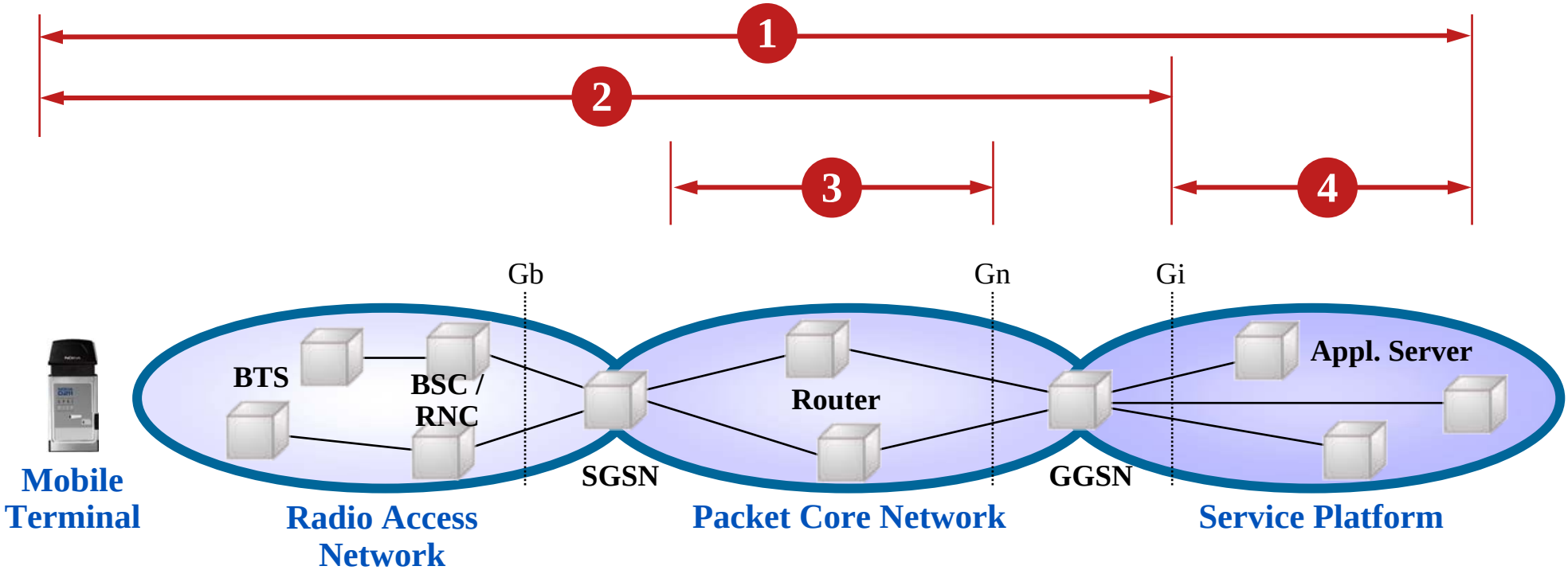
QoS monitoring tools: end-to-end



Centralize performance monitoring solution

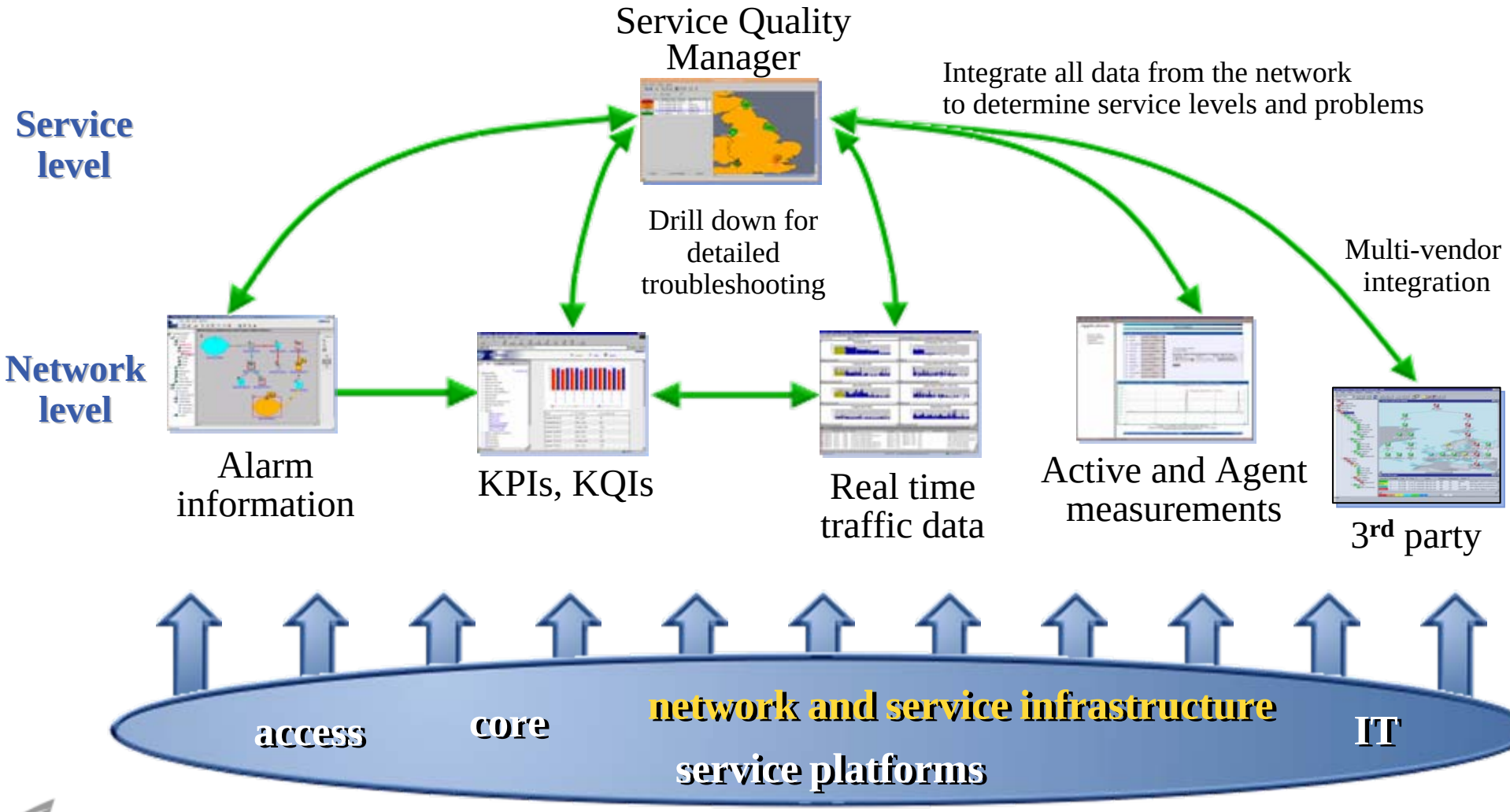


Active measurements: use cases



1. Verify QoE, e2e via MT connected to Stethoscope
2. Verify Mobile Network only (GPRS or 3G)
3. Verify IP Backbone (between Core Sites)
4. Verify Service Platform (services offered via AP)

Service Quality Manager: e.g. data sources



References

- D. Soldani, M. Li and R. Cuny (eds.), **QoS and QoE Management in UMTS Cellular Systems**, John Wiley and Sons, June, 2006, 460 pp.
  - http://eu.wiley.com/WileyCDA/WileyTitle/productCd-0470016396.html
  - http://www.connecting.nokia.com/NOKIA/nns.nsf/a/78786C61AB5A7C5AC225718F0026BAA3

    (Contact Mr. Geoff Farrell @ Wiley gfarrell@wiley.co.uk)

See also:

- http://lib.tkk.fi/Diss/2005/isbn9512278340/