QUALITY OF SERVICE IN HETEROGENEOUS NETWORKS

Kostas Pentikousis & Milla Huusko

OVERPROVISIONING: IT AIN'T BAD

Overprovisioning is not a new idea

Factor of safety (a.k.a. *factor of ignorance*)

Eighteenth century iron bridges had a factor of safety of 3-7x the calculated load

The *Harilaos Trikoupis* bridge connecting Rio-Antirio in SW Greece

OVERPROVISIONING (2)

Redundancy

RAID: increase fault tolerance/reliability and/or performance

Availability

A. S. Tanenbaum asks: when was the last time you picked up the phone and got a busy tone?

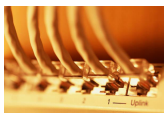
OVERPROVISIONING (3)

Ease of use

Memory garbage collection

Peak performance

Do you really need a dual core 64-bit CPU at 3 GHz?



Infinitesimal extra cost

Ride the Ethernet upgrade wave: $10 \rightarrow 10^2 \rightarrow 10^3$ Mb/s

Deploy 802.11a/b/g although either of the 3 would be more than enough

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OVERPROVISIONING vs. QoS

Overprovisioning

- "throw money at a problem" — inefficient, ineffective, wasteful
- sounds wrong

But, considering TCO, can it be that overprovisioning is the right thing?

Networkers need to determine if QoS is deployable?

- reliable?
- cost-effective?
- the only viable solution?

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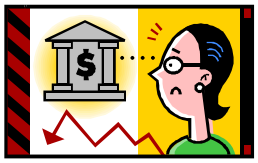
QoS vs. CHARGING

- QoS has been typically associated with tiered, e.g. bronze, silver, gold and platinum services, and policing/charging schemes



- Charging, the argument goes, is an effective means for enforcing QoS
- Flat pricing: *all* packets are marked as platinum

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QoS vs. CHARGING (2)

- QoS is by no means identical to tiered charging; it does not have to be amalgamated with tiered billing, and may have nothing to do with traffic per-packet charging

- QoS can provide the framework to deliver a service in the first place
- Case in point? Maxinetti, a triple play service (IPTV + VoIP + Broadband Internet access) offered in the metropolitan Helsinki area in Finland

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QoS AS A BUSINESS ENABLER: maxinetti

- End users pay X euros for a given IPTV channel package, Y euros for VoIP, Z euros for Internet access, or buy the bundle at a discount

- The operator, Maxisat, must differentiate flows from different services

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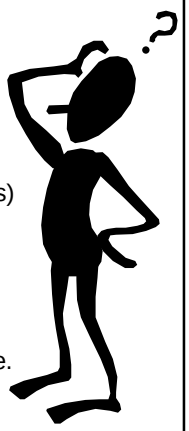
PRAGMATIC QoS

- Differentiating between classes of traffic is easier, more scalable
- More like traffic prioritization
- Given 8 Mb/s of downlink capacity, must provide
  - sufficient & sustained bandwidth (IPTV: 3-5 Mb/s)
  - low end-to-end delay for VoIP
  - low jitter for VoIP and IPTV
  - operational reliability and low packet loss rate
- Maxisat could have employed DiffServ, IntServ, or any other more elegant or sophisticated QoS scheme. They didn't.



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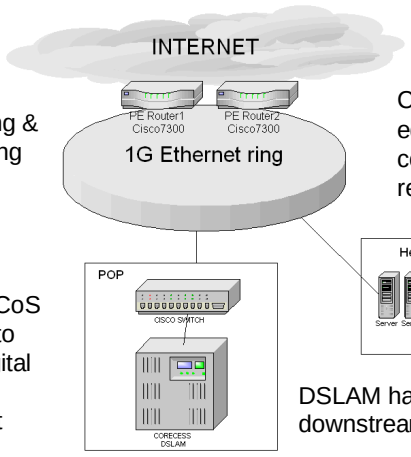
"QoS THAT WORKS"



Gigabit Song ring & residential cabling infrastructure

Cope with standard equipment (keep costs low, increase reliability)

Use IEEE 802.1P CoS and IP TOS fields to deliver bundled digital IPTV, VoIP and broadband Internet access

DSLAM handles downstream classification

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Maxinetti

- It works :) and shows that CoS may be enough and it should be the first step to a tier-service system.
- Maxisat opted for rudimentary downlink flow classification using CoS at Layer 2 and ToS at Layer 3 to provide end-to-end QoS
- Why? Reliability and cost effectiveness

- Yet this is a closed, homogeneous network infrastructure, under single administrative control
- What about end-to-end cross AD QoS? First, let's see what kinds of QoS frameworks exist

QoS IN CELLULAR NETWORKS

Generation	Frequency	Techniques	Data rate	QoS mechanisms
1st	450/900 MHz	Analogue	1.2 kbps	NO
2nd	900/1800/1900 MHz	CDMA & TDMA	9.6 kbps	NO
2.5	900/1800/1900 MHz	GPRS, EDGE, HSCSD	38.4-76 kbps	Available (not used)
3rd	2.0 GHz	WCDMA	up to 384 kbps	Available

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QoS MECHANISMS IN UMTS

- Versatile needs of applications lead to traffic prioritising
- Traffic can be divided into 4 QoS classes
  1. Conversational class
  2. Streaming class
  3. Interactive class
  4. Background class
- Biggest difference between these classes is the delay sensitivity

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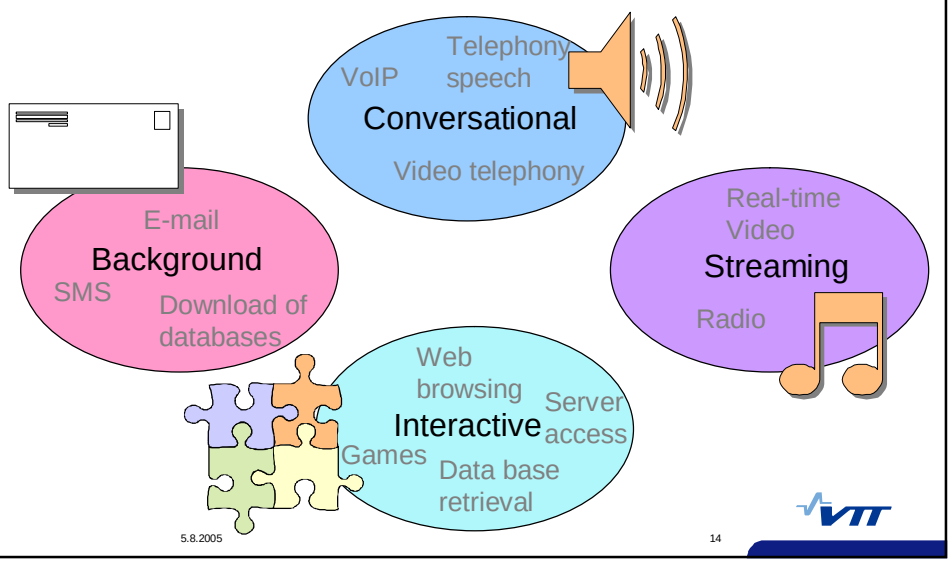
UMTS QoS CLASSES



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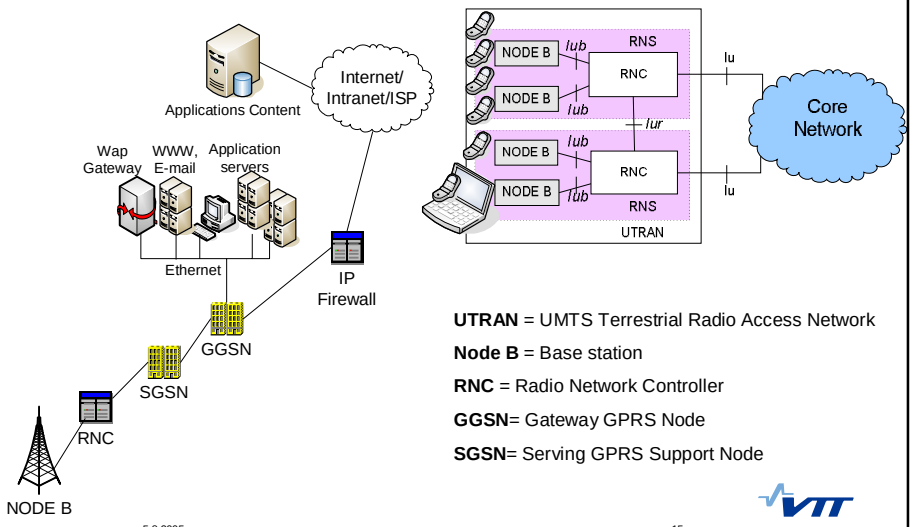
3G - Universal Mobile Telecommunications Service (UMTS) Architecture



UTRAN = UMTS Terrestrial Radio Access Network

Node B = Base station

RNC = Radio Network Controller

GGSN= Gateway GPRS Node

SGSN= Serving GPRS Support Node

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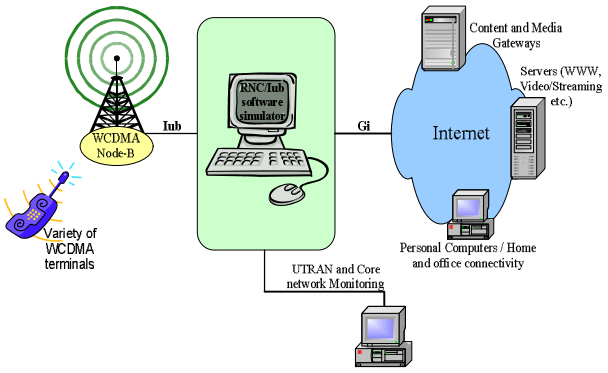
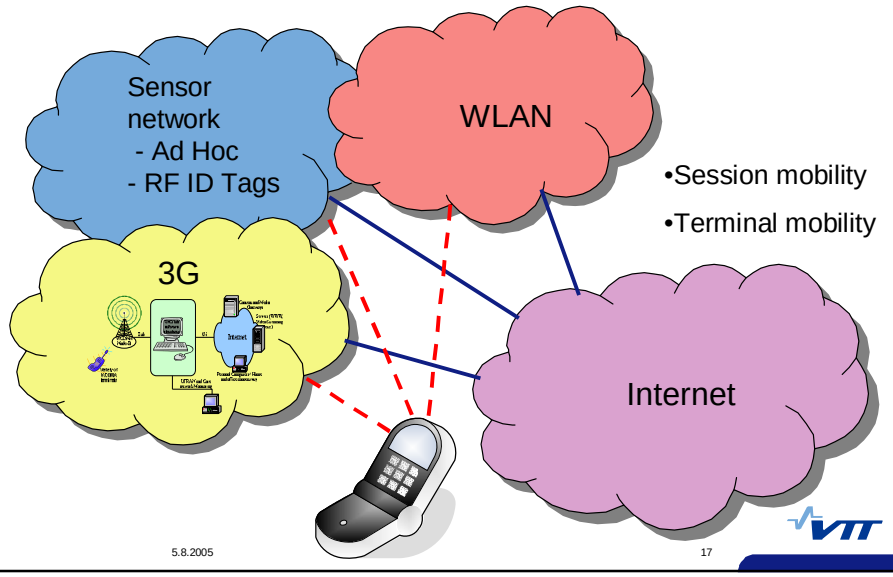
3G TEST PLATFORM

- Provides access for real WCDMA terminals to Core network and Internet
- Enables easily the end-to-end service testing in 3G environment
- Makes optimisation and enhancements of QoS-mechanism in UTRAN and Core network possible without intruding upon public network



Iub = UMTS interface between radio network controller and base station
Gi = Interface between gateway GPRS support node and external network

3G AND BEYOND TEST NETWORK



WLAN 802.11

- WLAN standards 802.11 a, b, c and g
  - physical layer of OSI
  - MAC sub layer
  - transparent interface for the higher layer users
  - existing network protocols run over IEEE 802.11 WLAN
- Physical layer
  - 802.11b: 11 Mbps in 2.4 GHz band
  - 802.11a: 54 Mbps in 5 GHz band
  - 802.11g: 54 Mbps in 2.4 GHz band

→ WLAN can be thought as a wireless version of the Ethernet, which provides best-effort service

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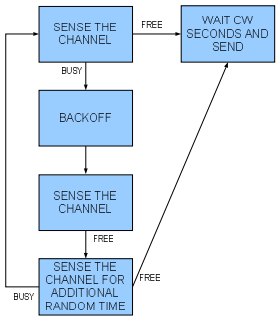
WLAN 802.11 (2)

- MAC-layer
  - IEEE 802.11c provides required information to ensure proper bridge operations, focusing on improving MAC layer for better bridging
  - IEEE 802.11e, 802.11f and 802.11i under standardisation process
  - IEEE 802.11e will provide enhanced QoS mechanisms
  - Distributed coordination function (DCF)
    - ”listen before talk”
    - works based on a Carrier Sense Multiple Access (CSMA)



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WLAN 802.11e

- Work is Final, waiting for approval
- Goal:
  - enhance the access mechanisms of IEEE802.11
  - provide service differentiation
- Enhanced DCF (EDCF)
  - extension of DCF
  - allows traffic to be classified into 8 different traffic classes, by modifying the backoff times

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MONITORING QoS

- Close to network traffic measurements
  - difference lays in the result analysing
- in QoS analysis network traffic is used as a tool to reveal the performance characteristics
  - delay
  - maximum throughput
  - jitter, etc.
- passive measurement methods
  - monitoring existing traffic
- active methods
  - traffic is generated for the measurements

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SUBJECTIVE QoS vs. OBJECTIVE QoS

- User experience is the one that counts!
- Subjective QoS is the service quality from the user perspective
  - measuring subjective QoS is done by user tests
    - only reliable way
  - Mean Opinion Score (MOS) tests are often used

  → expensive and time consuming
- Objective QoS
  - can be measured directly
  - can be used to estimate subjective QoS

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MONITORING TOOLS

- Network analyzers
  - Ethereal, Tcpdump, WinDump, Carnivore,…
- Packet capture libraries
  - Libpcap, WinPcap
- Monitoring tools
  - RTCP, RMON2, RTFM, …
- Usually monitoring tools are made to measure round trip parameters and not end-to-end parameters
- One way monitoring methods are needed

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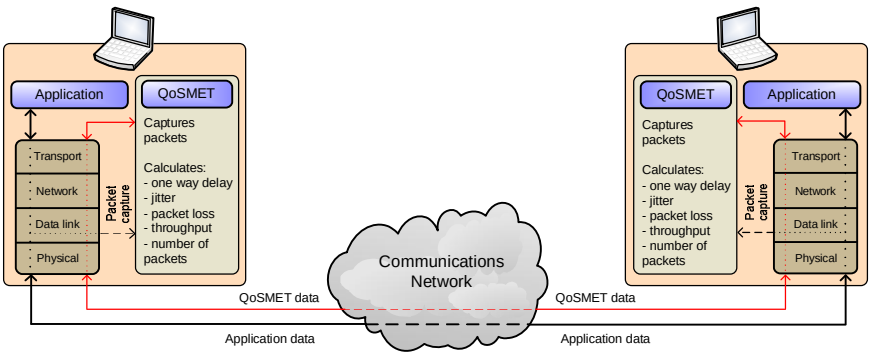
QoSMET – End-to-end QoS Monitoring Tool



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IEEE 802.1 Q & P

- MAC level protocols
- IEEE 802.1q
  - specifies a tag that appends to an Ethernet MAC frame. The VLAN tag has two parts:
    - VLAN ID (12-bit) and
    - Prioritization (3-bit). The prioritization field was not defined and used in the 802.1q VLAN standard.
- IEEE 802.1p
  - an extension of the IEEE 802.1q standard
  - enables Layer 2 switches to prioritize traffic and perform dynamic multicast filtering
  - 802.1p header includes a three-bit field for prioritization, which allows packets to be grouped into various traffic classes
  - 8 levels of priority

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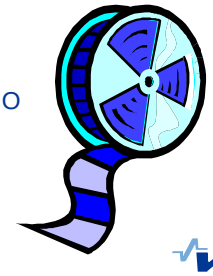
TIME FOR QoS THROUGHOUT THE STACK

- Intra- and, to some extent, inter-system handovers based on link layer metrics are commonplace in wireless networks
- We need to go further: session continuity
  - VTT demonstrated session continuity for streaming media between different devices (PC and IPAQ running Linux)

AMBIENT NETWORKS DEMO



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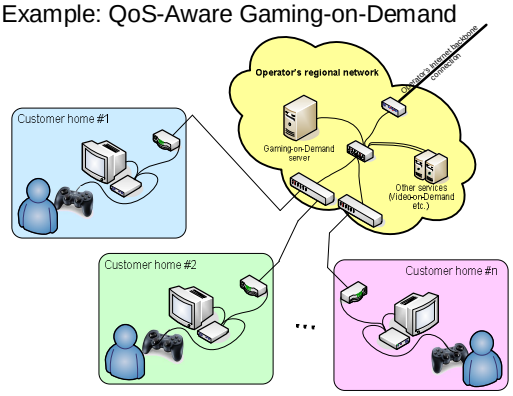
QoS THROUGHOUT THE STACK (2)

- Applications will need to incorporate some form of adaptation too (related work:MAGELLAN, PHOENIX)
- Example: QoS-Aware Gaming-on-Demand



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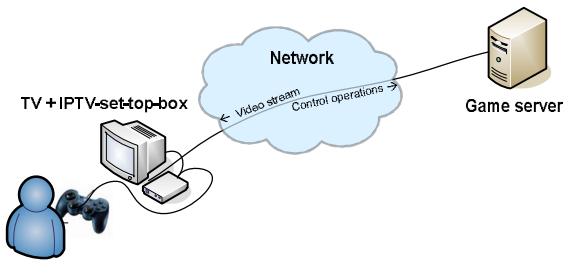
QoS THROUGHOUT THE STACK (3)

- Real-time video coding adaptation method for game service
- Network monitoring tool
- Real-time video encoding parameter optimization



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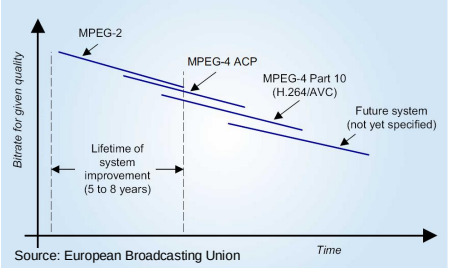
QoS THROUGHOUT THE STACK (4)

- Moore's Law is favorable to more efficient, but computationally expensive codecs
- Pattern of development cycles → efficiency gains



Source: European Broadcasting Union

- *at least two cycles to come after MPEG-4 Part 10*
  D. Wood, EBU

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QoS THROUGHOUT THE STACK (5)

- Conjecture: QoS in heterogeneous environments cannot be delivered with network-based QoS alone
- We can provide a certain level of QoS or adaptation at the two ends of the protocol stack
- What about the rest of the stack?
  - Underlying mechanisms need further study
  - Transport protocols, such as TCP, might need some new options. Example: *TCP User Timeout Option* (draft-ietf-tcpm-tcp-uto-01, July 2005)
  - Handovers cannot be solely based on link layer metrics (e.g. SNR). Why?

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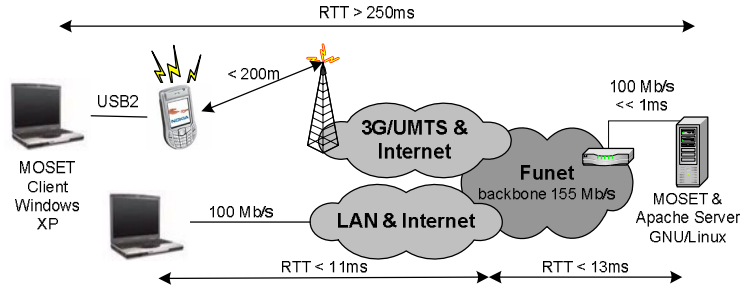
3G/UMTS DYNAMIC CAPACITY ALLOCATION



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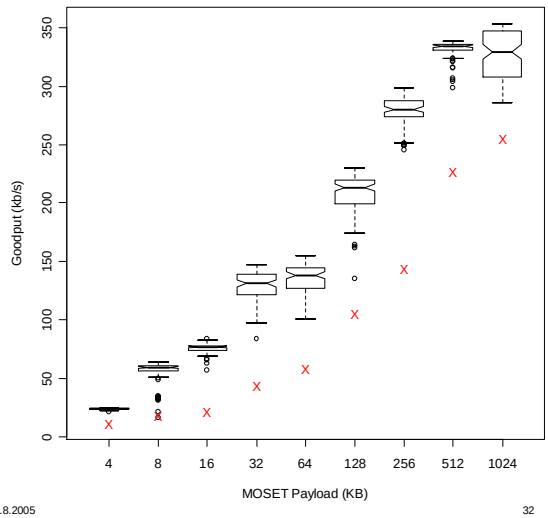
3G/UMTS: FIRST CONNECTION GOODPUT



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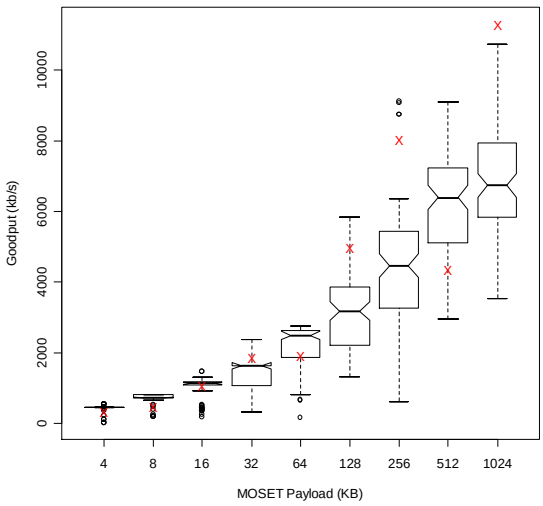
LAN: FIRST CONNECTION GOODPUT



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THE "PROPER" IP QoS

- *When unconditioned TCP-like traffic (i.e., traffic that slows down in the face of congestion) is mixed in with real time traffic (that keeps going despite congestion), both sides lose*

  — Carpenter & Nichols (2002)

- Need a QoS framework matching IP principles:
  - Network services (QoS) should *not* be designed for, or tied to a particular application
  - IP designers did not attempt to predict what applications will be using the network —neither should QoS designers
  - Provide the means to differentiate traffic and allow for network engineering

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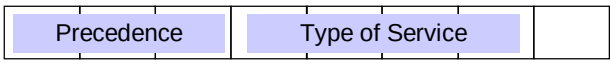
DIFFERENTIATED SERVICES ARCHITECTURE

- Scalable:
  - classification & conditioning *only* at boundaries
  - small set of forwarding behaviors
  - apply per-hop behaviors to aggregates of traffic

- Incrementally deployable
- Differentiation is asymmetric, decoupled from apps
- A refinement of the original *Precedence* model

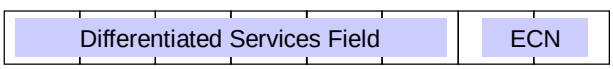
IPv4 CLASS-BASED DIFFERENTION

- RFC 791 [1981] and RFC 1812 [1995]



- RFC 2474 [1998]

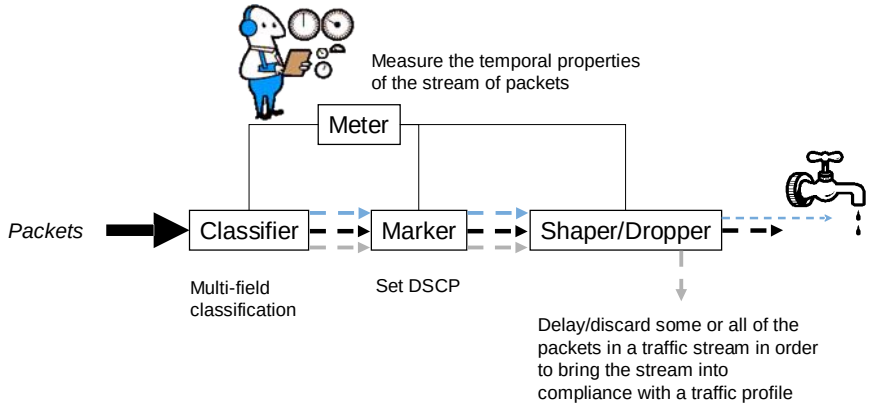
- RFC 3168 [2001]



SERVICE SPECIFICATION & PHBs

- Service level specification (SLS): set of parameters and their values which together define the service offered to a traffic stream by a DS domain
- Traffic conditioning specification (TCS): set of parameters and their values which together specify a set of classifier rules and a traffic profile
  - TCS: integral element of an SLS
- Per-hop Behaviors (PHB):
  - Default; best effort
  - Class selector
  - Expedited forwarding (EF); "virtual leased line"
  - Assured forwarding (AF)

TRAFFIC CLASSIFICATION & CONDITIONING



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DiffServ ARCHITECTURE

- Minimalist — *sophisticated simplicity*
- Separation of control and forwarding (like in IP)
- Supported by all major vendors in mid- and high-end routers
- Inter-domain, bilateral agreements
- For inter-AD traffic, perhaps the only pragmatic, standardized framework in actual deployment
- Nevertheless, deployment is not widespread
  - Non-technical obstacles

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DiffServ: STILL RELEVANT?

- By the time RFCs 2474 & 2475 were released in December 1998
  - Asia: the financial crisis was in full swing
  - USA: the major issue was the Monica Lewinsky scandal
  - Europe: the euro did not exist
  - Wall Street: *irrational exuberance* ruled

- In mid-June, crude oil set a 12-year low: it averaged $10.11 per barrel—half of the official OPEC target of $21
- 1998 birthdays:

  Windows 98, iMac, Celeron, and Google

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SLOW DEPLOYMENT

- The Maxinetti case shows that class-based differentiation is deployable, allows for new services, and can be profitable
- That is exactly what DiffServ was all about
- So why is public deployment of DiffServ soooo slow?

- Need inter-provider agreements (*cf.* VPN)
- Need to demonstrate the benefits(?) of QoS
- Need to enforce consistent policies
- Overprovisioned backbones
- QoS is costly and can lead to operational overhead for providers
- No common, well-understood service definitions
- Your reason here :)

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OPEN ISSUE: WHO NEEDS QoS?

- L3 virtual private networks (VPN)?
  - Most of the DiffServ deployments
- Network games? Henderson & Bhatti (2003):
  - Many and successful net games… using best effort only
  - Throughput not an issue, delay is
  - Reported delays deter users from joining a server
  - Delay increases while playing do not force users to leave in droves despite the noticeable degradation in their gaming performance
- Would gamers pay for QoS?
  - Yes, if included in the price of the game
  - No, if it was offered as a "premium" service

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OPEN ISSUE: WHO NEEDS QoS? (2)

- VoIP
  - Skype is already making VoIP reality without any QoS and you only need a dialup connection
  - Why would a user pay more for her VoIP packets? She wouldn't. But she would go for a Maxinetti kind of service which is cheap and hip :)
  - And that is our view: QoS frameworks should be seen as enablers, not as cash cows

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QoS WITH FLAT PRICING???

- *QoS is about allowing the user to select between quantitative performance guarantees*

  — Crowcroft et al. (2003)
- Personal opinion
  - QoS as a service enabler which brings new products in the market
  - Unchain QoS from "cost linked to quality"
  - Marketing should be about a service not the technology
- Those familiar with "all-you-can-eat" buffets most certainly appreciate the simplicity in pricing
- Yet, when one starts talking to me about QoS I check that my wallet is in place…

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QoS WITH FLAT PRICING!!!

- *Free nights and weekends* has been quite a common offering from US cellular operators for years now
- Vonage, Cablevision offer unlimited US & Canada calls
- Do these schemes hurt revenues? Decrease profits?
- How much can one "eat" anyway?

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OPEN ISSUE: OPERATIONAL COMPLEXITY

- Based on his operational experience Bell (2003) argues that
  - Network Operation Center personnel have come to believe that complex protocols destabilize a network, mainly due to buggy implementations
  - Case in point: introducing multicast in the LBNL network led to difficult to trace bugs
  - Amplification and Coupling principles
- IP multicast as a limit-case: Any QoS framework should be less complex that multicast in order to gain wide adoption
- As such, IntServ is pretty much done

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OPEN ISSUE: OPERATIONAL COMPLEXITY (2)

- Overprovisioning to the rescue: simple and economical
- The "10% rule"
- Deal with network congestion

Throw bandwidth at the problem
or
Throw protocols at the problem

- There are case, though, that bandwidth simply cannot be thrown at the problem

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OPEN ISSUE: TRAFFIC CLASSIFICATION

- Traffic classification
  - The end hosts are the natural points, but due to lack of trust and maintaining administrative control, gateways are preferred by NOCs
  - Dynamic classification of packets into different classes is not a trivial task
  - Inhibits QoS deployment
- M. Roughan, et al. (2004):
  - Framework for scalable, dynamic traffic classification based on statistical application signature
  - Obtain signatures insensitive to the particular application protocol

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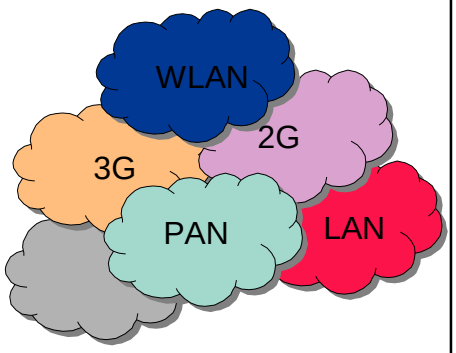
END-TO-END QoS IN HETEROGENEOUS NETWORKS

- Network heterogeneity =>Quality of Service has to be deployed end-to-end
- QoS schemes in IP Networks
  - Best Effort
  - Integrated Services (IntServ)
  - Differentiated Services (DiffServ)
- WLAN QoS
  - IEEE 802.11e being finalized
- Service Level Agreements (SLA)
  - adjusting QoS classes of different networks
- No End-to-End method standardised yet
- Application used by the User Equipment should be able to specify its QoS needs



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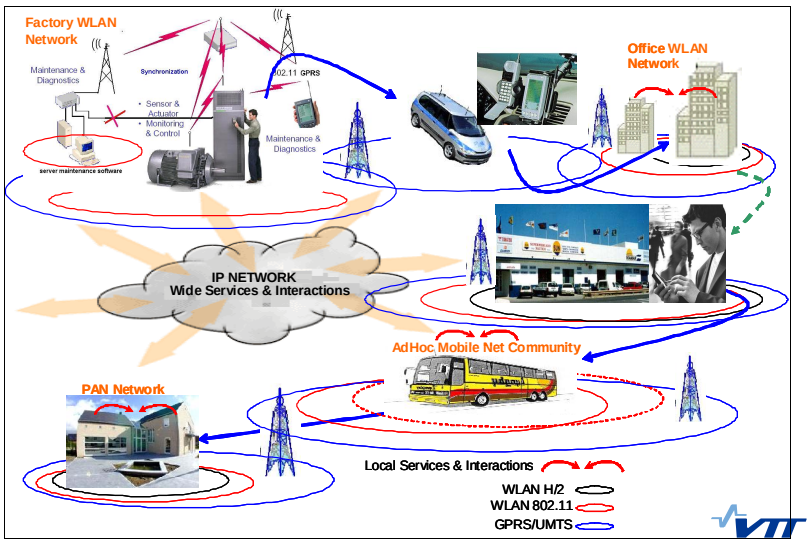
EUREKA/ITEA EASY WIRELESS PROJECT



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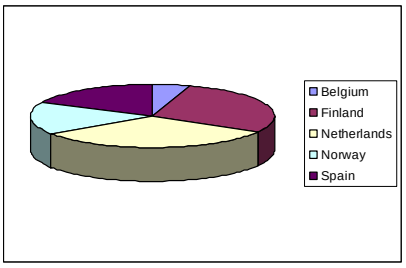
Easy Wireless

Allow seamless roaming between wireless networks while maintaining Quality of Service

- **EUREKA/ITEA** project
  - ITEA is a project clustering organisation
  - funding from each country
- 16 partners from 5 countries
- Sept. 2004-Sept. 2007
- Total budget: **12 Million €**
- **Partners**
  - Thales Communications
  - Telefónica
  - 4 Universities
  - 5 SME's
  - 4 Research Centres



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- 3GPP2—3rd Generation Partnership Project 2: www.3gpp2.org
- IEEE P802.11 - TASK GROUP E

  http://grouper.ieee.org/groups/802/11/Reports/tge_update.htm

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