a broadband incentive solution

re-feedback

Bob Briscoe, BT Research

Nov 2005

CFP broadband incentives w-g

an architectural solution

- bb incentive problem
  - may require institutional solutions, but...
- Internet architecture must also get its house in order
  - lack of accountability long been a criticism
    - re-feedback adds accountability for causing congestion
  - e2e principle prejudged the outcome of a mega-tussle
    - computer industry would take the value add
    - network infrastructure firms were cut out of the game
- re-feedback designed for tussle
  - right information in the right places for tussle to commence
  - but playing field no longer tilted
  - re-feedback gives joint control to ends and edges
  - without reducing the potential for ‘responsible’ innovation
- our aim
  - ISPs can dream up incentive-compatible service plans
  - but with flat pricing

relevance to bb incentive problem

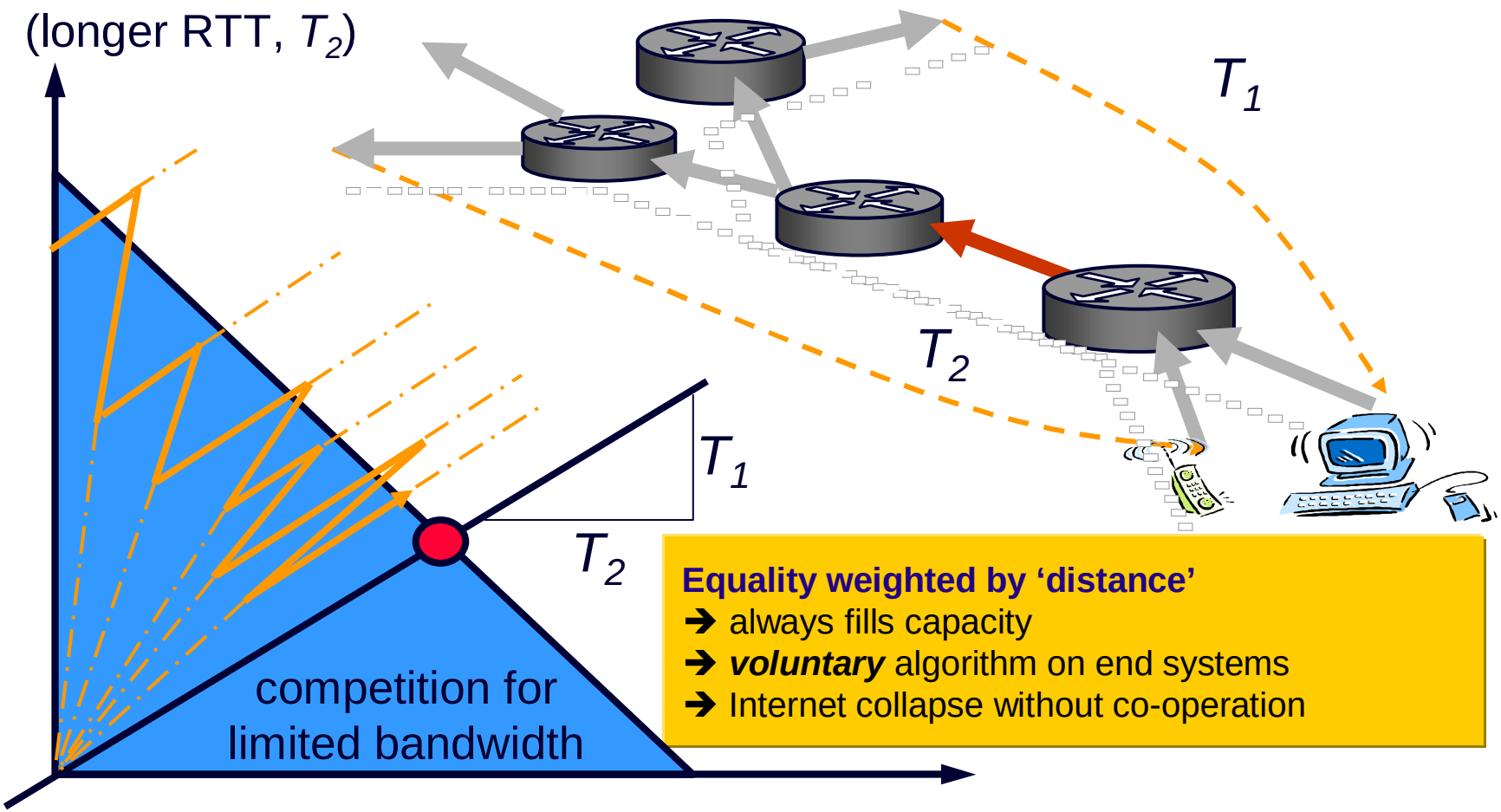
bb incentive problem

- supply
  - infrastructure investor
    - disintermediated from added value
- demand
  - traffic variability growing with capacity
    - variability across users
      - discriminate heavy/light users?
    - variability across time
      - peaks and troughs growing

re-feedback solves

- supply
  - infrastructure can enforce hooks into value of apps it doesn't own
  - non-discriminatory
    - behaviour using infrastructure resources, not what the app is
  - de-risks operator investment
- demand
  - front-loaded congestion-based metric
    - flat rate tiering with spongy quotas
      - see tariff examples
    - optimising all services together
      - nanosec timescales
- bonus:
  - a new personal bb model
  - a simpler QoS mechanism

business model of TCP



Equality weighted by 'distance'

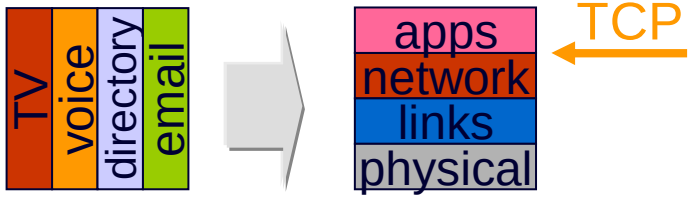
➔ always fills capacity

➔ ***voluntary*** algorithm on end systems

➔ Internet collapse without co-operation

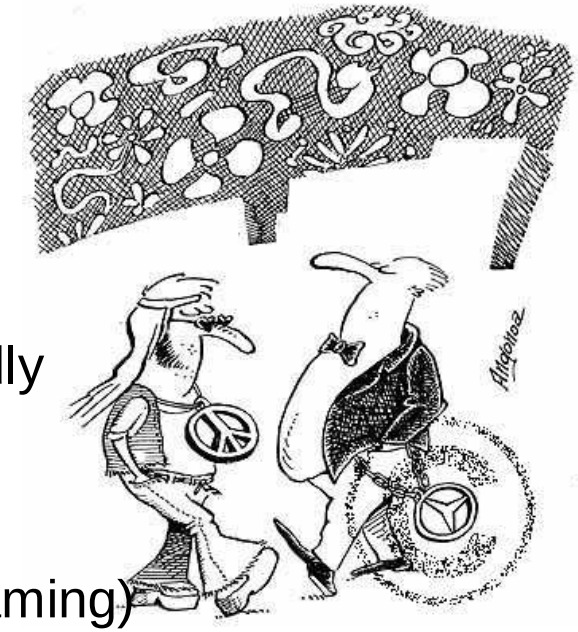
TCP: a large part of the bb incentive problem

- TCP as wallpaper
  - we forget it's there
- TCP allocates resources fairly between 'elastic' apps
  - rail timetables, e-mail, TV listings, music downloads, genealogy searches, chat, software patching, electronic data interchange, ...
  - global fair resource allocation *without asking the network*
  - enabled incredible innovation
  - but (because?) disintermediated network resource owner
  - overnight commoditisation of data transport



- not proposing to turn the clock back
  - but learn from the experience...

TCP is too nice



courtesy of cartoonstock.com

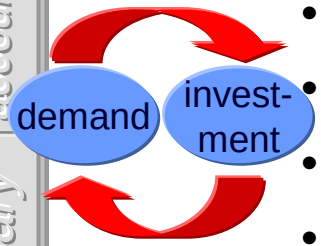
- TCP assumes everyone else is TCP-friendly
  - backs away from TCP-hostile apps
- real-time interactive apps (audio, video, gaming)
  - if unresponsive to congestion, get to keep whatever they need
  - r-t apps take more than fair share *without asking the network*
  - aggression pays
- huge r-t apps market may haemorrhage away (as TCP apps did)
  - £34B in UK alone
  - Skype, Vonage may commoditise market too early
- revenue to infrastructure of TCP-hostile apps is *less than cost*

TCP fights back

- if only...
  - networks could police TCP friendliness
  - and it were simple and cheap to be non-TCP friendly
- TCP-friendly as default
  - for already commoditised apps

"Remember, if we run into any trouble, our placards are attached to bats."

- non-default congestion response: must ask network
  - gives networks hook into revenue from r-t apps they don't own
  - de-risks infrastructure investment
  - closes virtuous supply-demand circle
  - justifiable resource allocation - not anti-competitive*

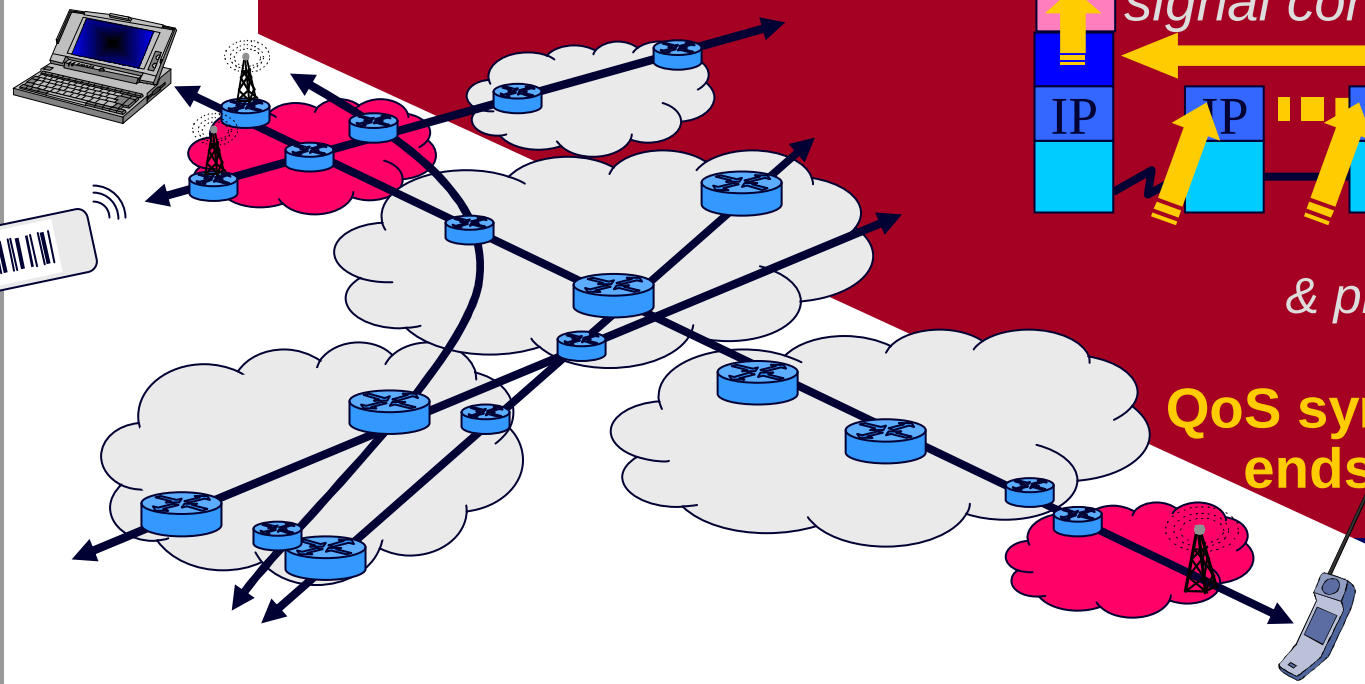


* could infer app & price discriminate (1 audio bit worth 1000 video bits)

congestion response ≡ QoS

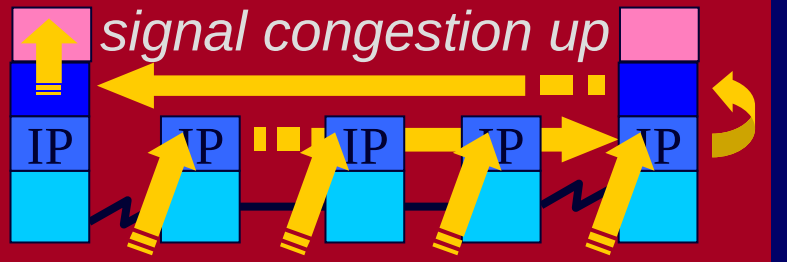
😐 **traditional**
optimise ea subnet separately
e.g. Diffserv (open-loop)

☺ **new**
optimise all paths together



signal req's down
& price req's

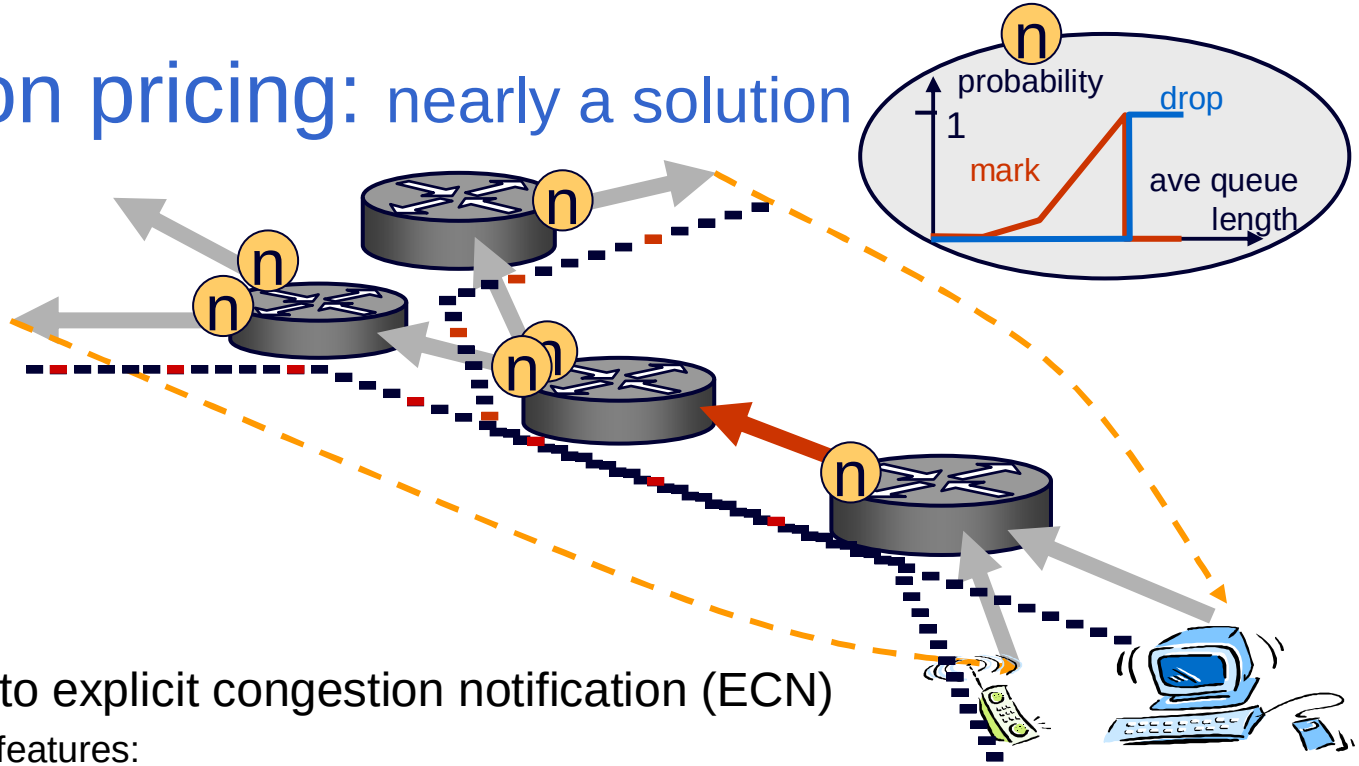
signal congestion up



& price congestion

QoS synthesised by the ends (closed-loop)

congestion pricing: nearly a solution



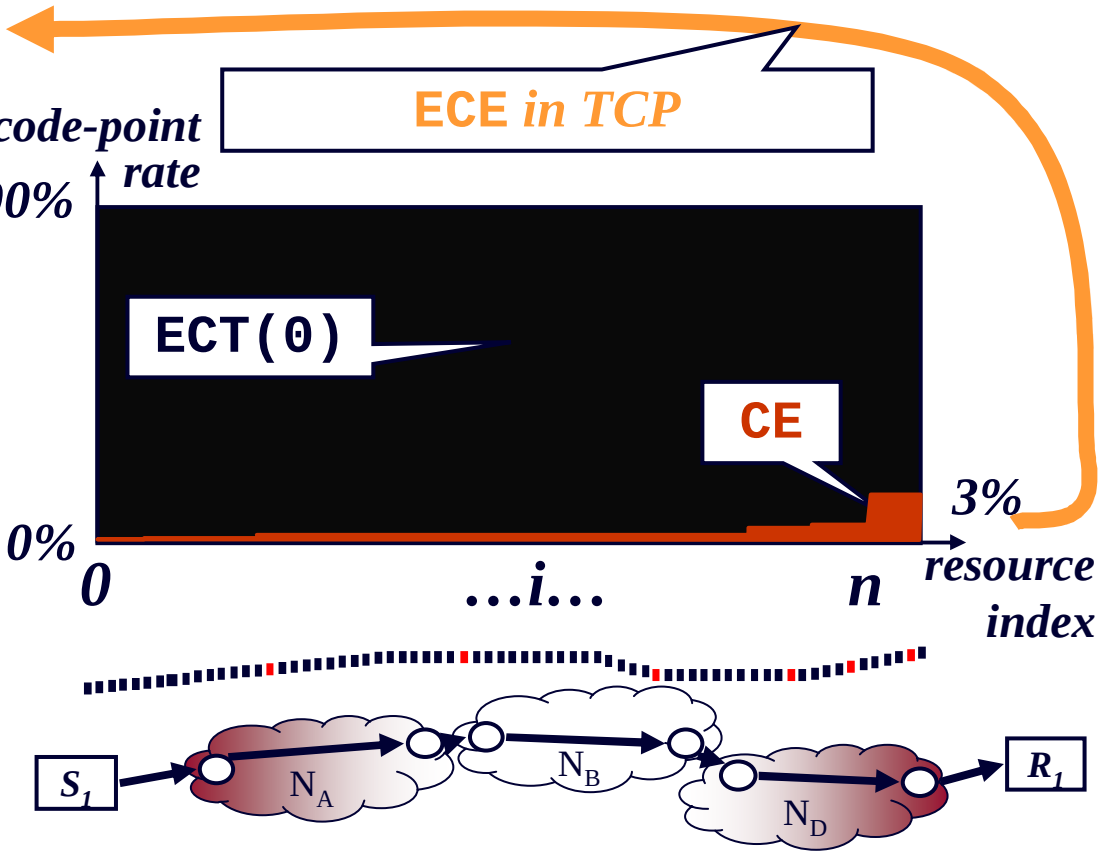
- apply price to explicit congestion notification (ECN)
  - some nice features:
    - ✓ as load variance increases, congestion pricing superior to volume pricing
    - ✓ per-packet congestion pricing makes strategising agents optimise network fill and social welfare
    - ✓ metering implicit congestion was infeasible (dropped packets)
    - ✓ ECN in TCP/IP already proposed IETF standard (2001)
    - ✓ can apply price to pre-congestion, before quality degrades
- but...
  - × a few show stoppers

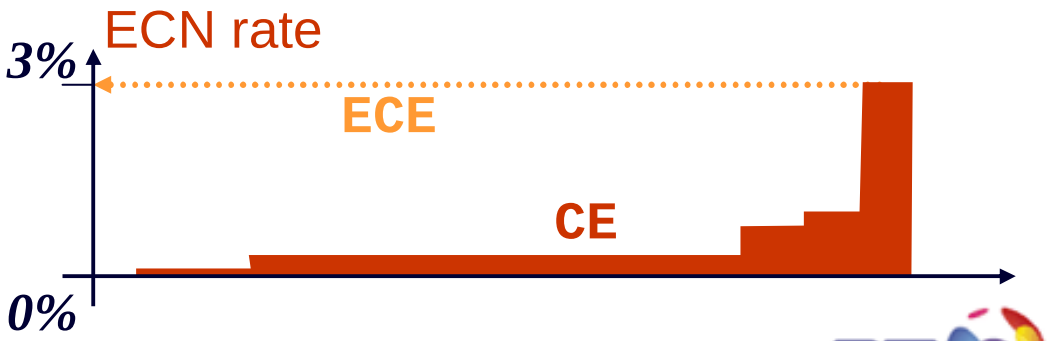
ECN (recap)

2-bit ECN field in IP header

code-point	standard designation
00	not-ECT
10	ECT(0)
01	ECT(1)
11	CE

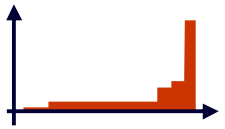
ECN: explicit congestion notification
ECT: ECN-capable transport
CE: Congestion experienced
ECE: Echo congestion experienced





ECN show-stoppers for congestion pricing

- don't only want congestion 'price' for direct charging
  - should be able to drive internal network policing mechanisms (cf. TCP)
- ECN emerges at wrong end of network
  - for charging: have to charge receiver
  - for policing: have to police after the damage has been done



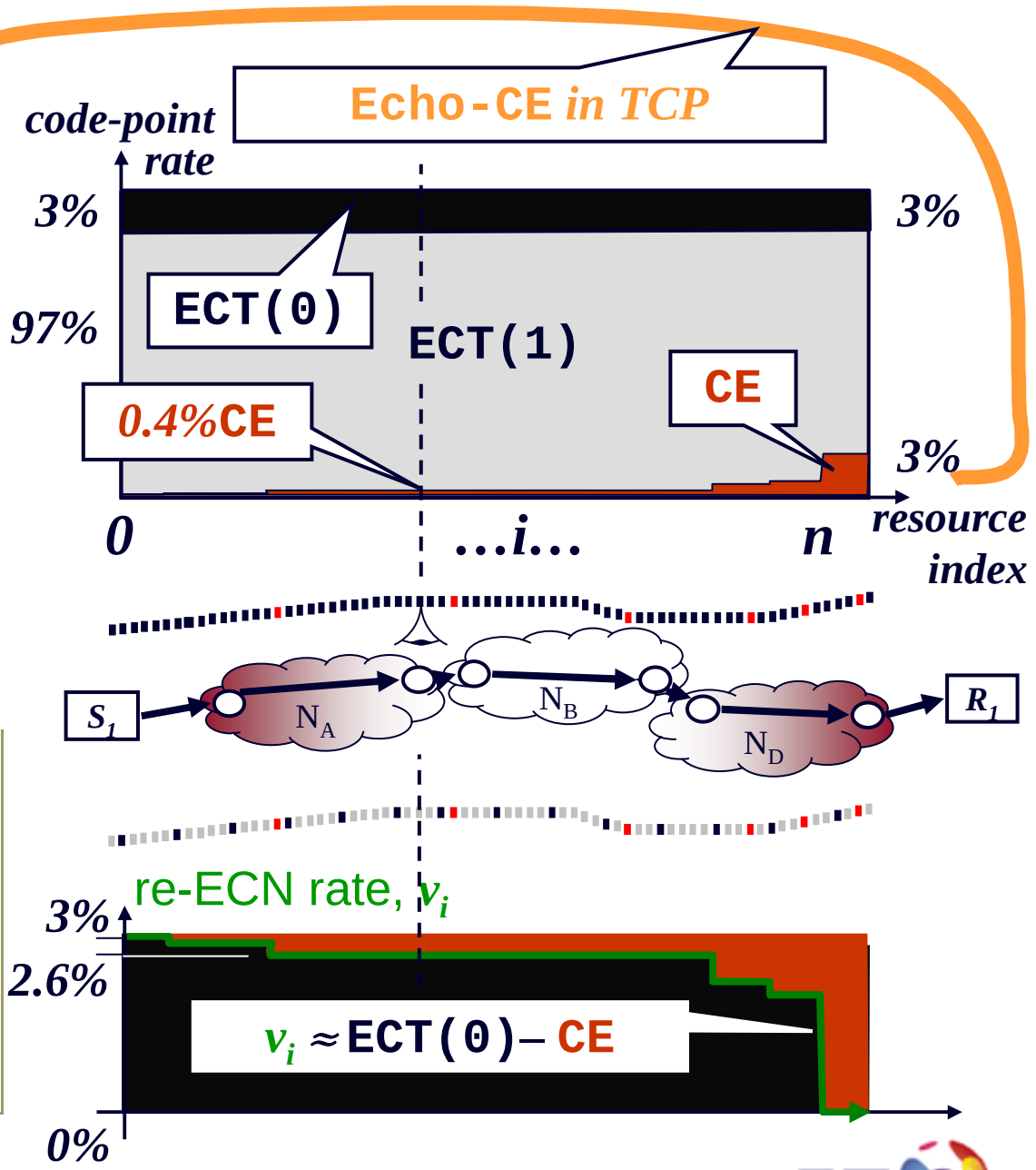
- feedback channel not accessible to ingress network either
  - end hosts can use IPsec to encrypt higher layers
  - or not use feedback at all (unresponsive to congestion)

- why not charge receiver to incentivise e2e charge to sender?
  - denial of funds attacks
  - requires dynamic charging (cannot internalise dynamics within network)
  - customers highly averse to dynamic charging
- outcome:
  - only ECN-based incentive-compatible model, requires receiver congestion charging

re-ECN
(sketch)

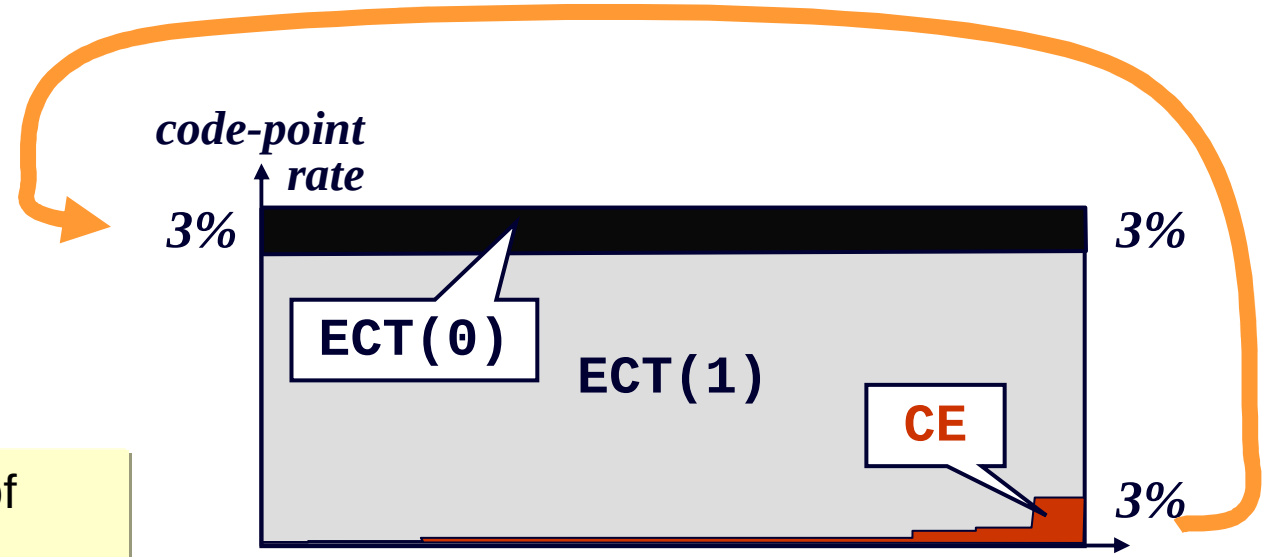
code-point	standard designation
00	not-ECT
10	ECT(0)
01	ECT(1)
11	CE

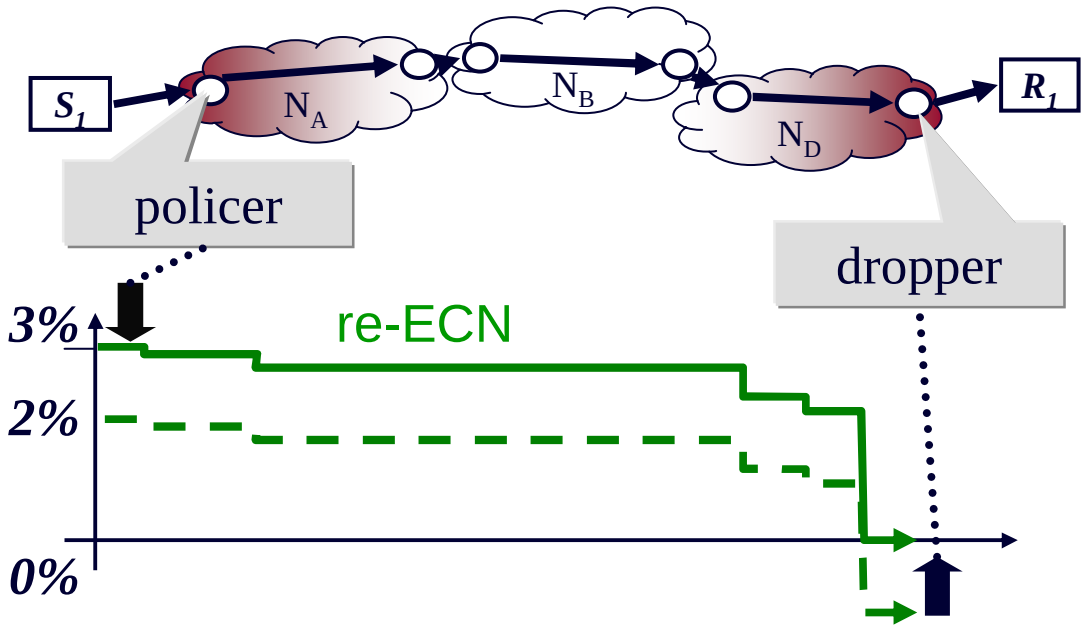
- on every **Echo-CE** from TCP, sender sets **ECT(0)**, else sets ECT(1)
- at any point on path, diff betw rates of **ECT(0)** & **CE** is downstream congestion
- routers unchanged



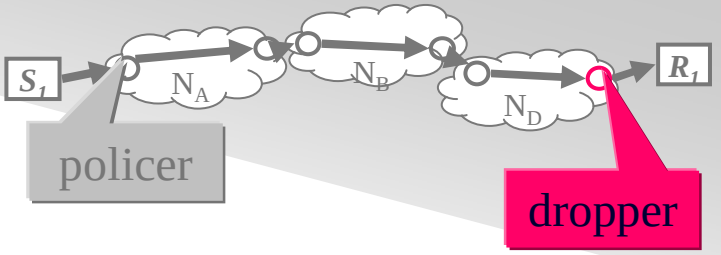
incentive framework
(user-network)

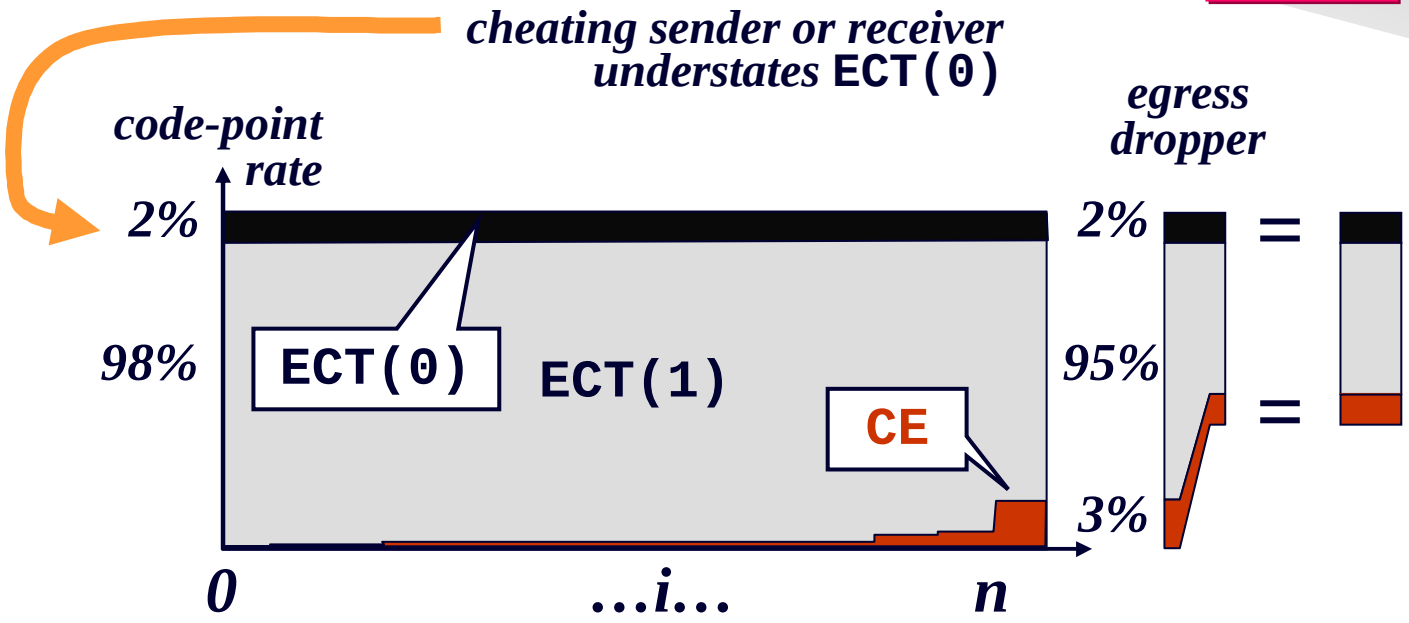
- packets carry view of downstream path congestion to each router
- so ingress can police rate response
  - using path congestion declared by sender
- won't snd or rcv just understate congestion?
- no – egress drops negative balance



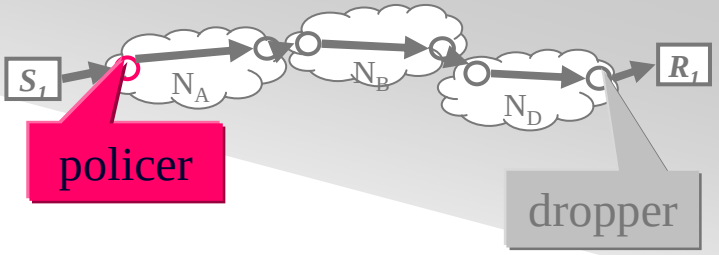


egress dropper (sketch)





- drop enough traffic to make rate of **CE** = **ECT(0)**
- goodput best if rcv & snd honest about feedback & re-feedback
- simple per pkt algorithm
  - max 5 cmp's, 5 adds, 1 shift



ingress TCP policer

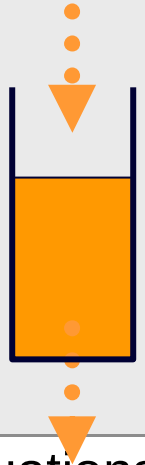
- packets arrive carrying view of downstream path congestion
- can police to any desired rate equation, eg TCP
- token bucket implementation: drop whenever empties
  - bounded flow-state using sampling

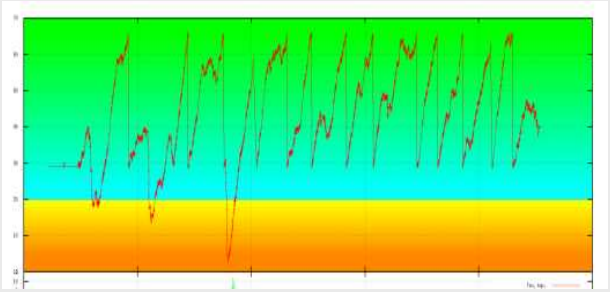
compliant rate

$$x_{TCP} \approx \frac{ks}{T\sqrt{p}}$$

actual rate

$$x = s/\Delta t$$



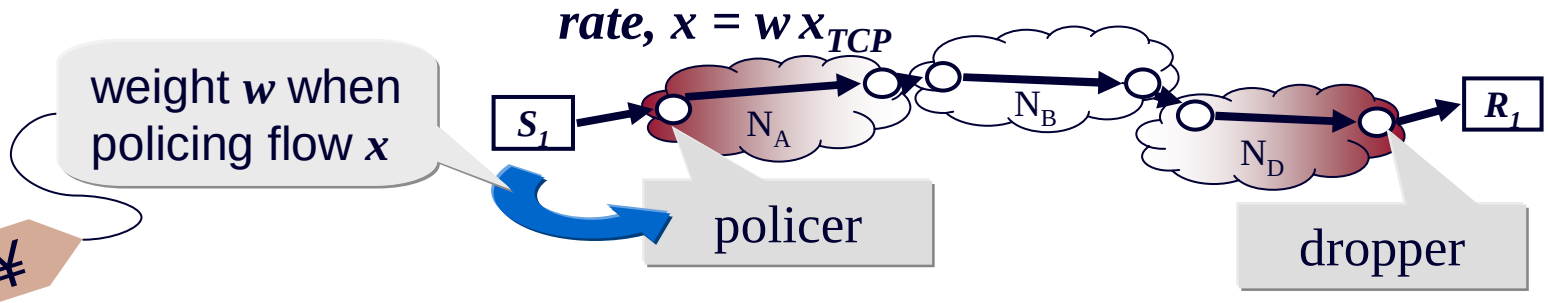


k	$\sqrt{(3/2)}$
s	packet size
T	RTT
p	marking rate
Δt	inter-arrival time

- above equations are conceptual, in practice can re-arrange
  - you get ***1/p*** by counting bytes between **`ECT(0)`** marks
  - high perf. root extraction per **`ECT(0)`** mark challenging (like pulling teeth)
- for RTT need sister proposal for ‘re-TTL’ (tba)

simpler, cheaper & more flexible QoS

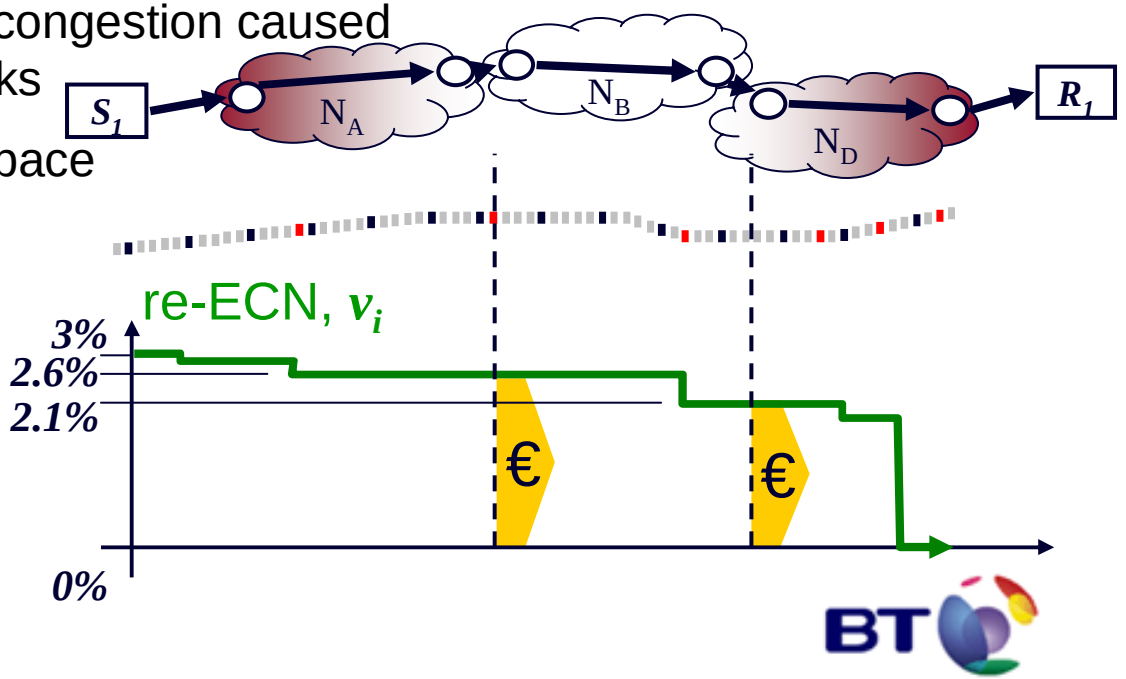
- sender can request better rate response from policer



- recall: permissive rate response to congestion ≡ QoS
  - traditional QoS: routers give certain packets priority during congestion
  - allowing an app to maintain its rate during pre-congestion is equivalent
  - zero rate response to congestion ≡ QoS reservation
- allows ingress to offer QoS *unilaterally*
  - without asking downstream networks
  - no need for standard business models: enables market innovation

how can ingress offer QoS unilaterally?

- inter-domain congestion charging
  - bulk volume of **ECT(0)** less bulk volume of **CE**
  - measure of downstream congestion allowed by upstream nets
  - aggregates and deaggregates precisely to responsible networks
  - upstream networks that sell more QoS automagically pay for congestion caused in downstream networks
  - adaptive apps make space within available capacity
  - congestion charging revenue stream funds infrastructure upgrade



re-feedback
enables incentive-compatible retail pricing

- our aim: range of incentive-compatible service models
  - but with flat pricing
  - customers averse to dynamic charging
    (previously the only incentive-compatible model)
  - but we don't want flat rate approximations to blunt the incentives
- re-feedback provides downstream congestion metric
  - downstream information upstream
  - basis for pricing and service innovation
- example #1: single flat rate with congestion quota throttle
  - flat subscription pays for a quarterly quota of congestion
  - as the moving weekly average approaches 1/13 of the quota
    the weight of the user's policer reduces (becomes stricter)
    - lower bit rate for same congestion – uses up quota more slowly
  - cf. fair allocation of bandwidth (FAB), but for congestion not volume
  - use of uncongested paths unaffected by throttle

re-feedback
more incentive-compatible retail pricing models

- example #2: tiered QoS at flat rates, each with congestion quota throttle
  - subscription effectively buys congestion quotas for a set of tiers
  - higher tiers can use a higher weight policer (more permissive)
  - applications configured to use a relevant tier (QoS class)
  - the more of each quota is used, the less the QoS improvement in that tier
  - options:
    - boost an application into a higher tier
    - move quota between tiers
    - one-off payment to bump up a quota
- example #3: per-session charging (perhaps 800-type service)
  - when congestion rate would lead to greater congestion ‘cost’ than revenue policer invokes admission control (effectively avoids making a loss)
- example #4: congestion charging (perhaps plus capacity charge)

the problem: accountability for causing congestion

- main concern
  - non-compliance with e2e congestion control (e.g. TCP-friendly)?
  - how can ingress network detect whole path congestion? and police congestion control?
- not just per-flow congestion response
  - **smaller:** per-packet
    - single datagram ‘flows’
  - **bigger:** per-user
    - a congestion metric so users can be held accountable
    - 24x7 heavy sources of congestion, DDoS from zombie hosts
  - **even bigger:** per-network
    - a metric for holding upstream networks accountable if they allow their users to congest downstream networks

re-feedback

other accountability applications

- user-network
  - congestion-history-based policer (congestion quota throttle)
    - throttles causes of past heavy congestion (zombies, 24x7 p2p)
  - correct flow-start incentives
    - including short flows and single packets (messaging apps)
  - DDoS mitigation
- network-network
  - load sharing, traffic engineering
    - multipath routers can compare downstream congestion
  - bulk metric for inter-domain SLAs
    - alternative to congestion charges
  - upstream networks that do nothing about policing, DoS, zombies etc will break SLA or get charged more

reading and/or related work

- Jeffrey MacKie-Mason (UMich) & Hal Varian (UCB) “Pricing the Internet” (1993)
  - Smart Market idea of placing bids in packets
  - admitted it was impractical – also poor feedback
- David Clark (MIT) “Combining Sender and Receiver Payments in the Internet” (1996)
  - decrementing payment field in packet – no e2e feedback
  - no separation between technical metric and price to apply to it
- Frank Kelly *et al* (Uni Cam), “Rate control for communication networks: shadow prices, proportional fairness and stability” (1998)
  - the game theoretic basis of Internet congestion pricing, but with the direction of payment the wrong way round
  - consequently needs retail dynamic pricing
- Richard Weber & Costas Courcoubetis "Pricing Communication Networks,“ Wiley (2003)
  - v useful theoretical background
- Bob Briscoe & Steve Rudkin (BT), “Commercial Models for IP Quality of Service Interconnect,” in BTTJ Special Edition on IP Quality of Service, 23(2) (Apr 2005)
- Bob Briscoe *et al* (BT, UCL & Eurécom), “Policing Congestion Response in an Internetwork using Re-feedback,” in Proc ACM SIGCOMM'05, CCR 35(4) (Sep 2005)
- Bob Briscoe (BT & UCL), Arnaud Jacquet and Alessandro Salvatori (BT), “Re-ECN: Adding Accountability for Causing Congestion to TCP/IP,” IETF Internet-Draft <draft-briscoe-tsvwg-re-ecn-tcp-00.txt> (Oct 2005)
- http://www.cs.ucl.ac.uk/staff/B.Briscoe/pubs.html

BT

re-feedback: a solution to the bb incentive problem

summary

- TCP enabled innovation with responsibility
  - but commoditised huge numbers of apps overnight
- TCP apps too nice to irresponsible apps
  - could commoditise rest of Internet value (€$£¥ Bn)
- ECN & congestion pricing nearly solve bb incentive problem
  - apply pricing to congestion
  - incentivises smoothing of variance in load across users and time
  - but wrong end of network – requires dynamic charging
- re-ECN allows TCP to fight back
  - allows ingress to police TCP-fairness
  - and adds accountability for causing congestion to the Internet
- re-ECN enables incentive-compatible but flat retail pricing
- re-ECN becomes low cost interface for QoS
  - ingress network can act unilaterally given inter-domain congestion charging

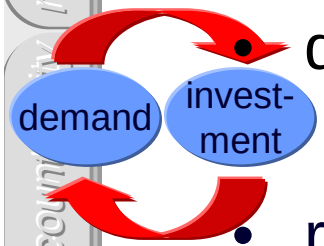
BT

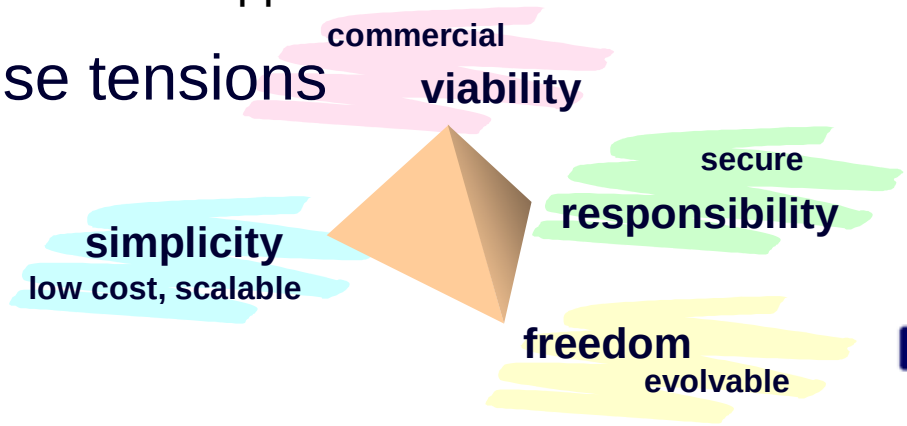
re-feedback: a solution to the bb incentive problem

designed for tussle

"Remember, if we run into any trouble, our placards are attached to bats."

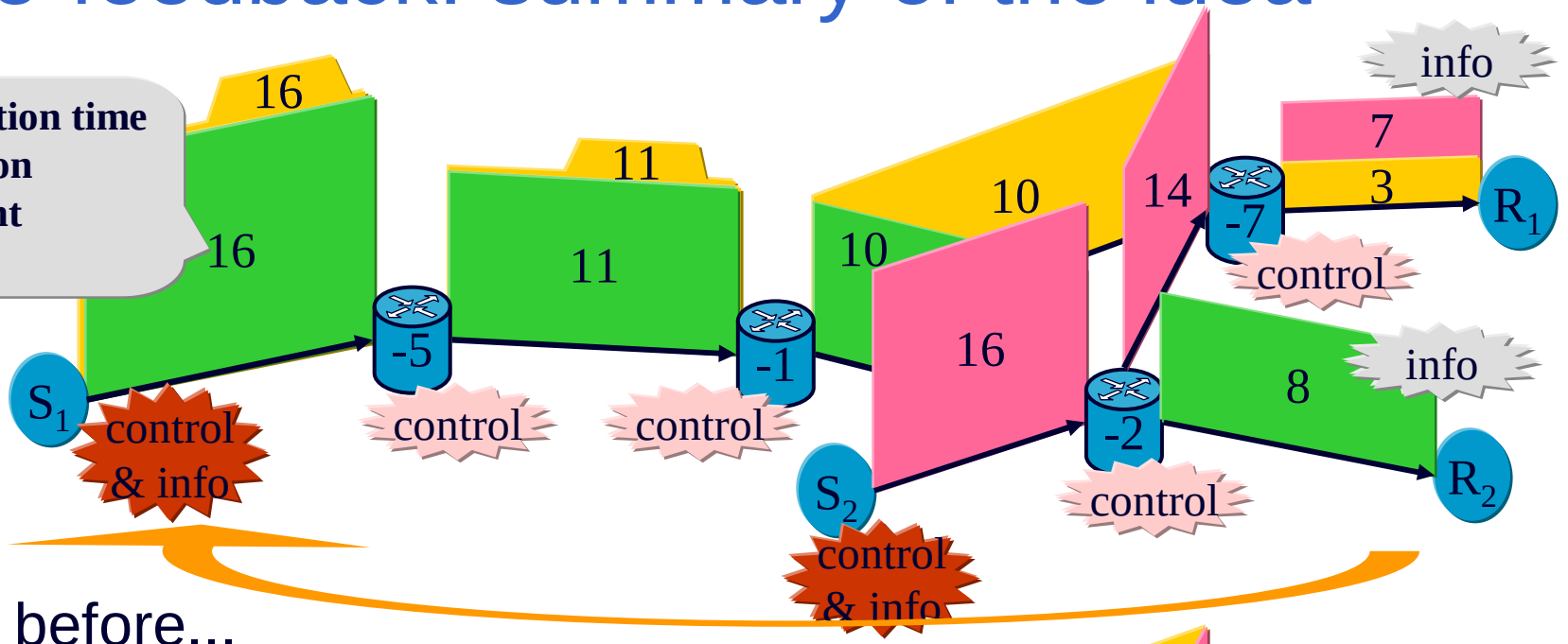
- joint control between host and network
  - tussle between computing & network industries
- network can limit irresponsible innovation
  - allows Skype's responsible innovation
  - prevents the irresponsible part (pushing in without asking)
- de-risks infrastructure investment
  - hook to revenue from apps the network doesn't own
- resolves all these tensions





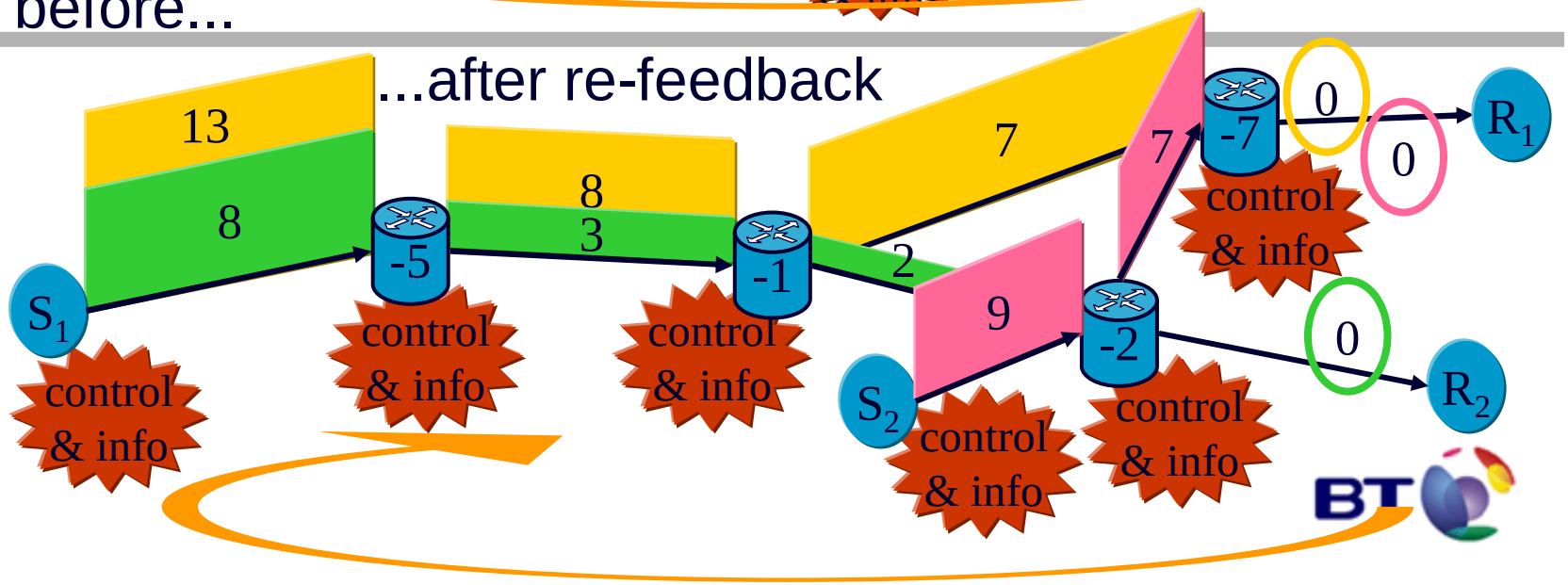
re-feedback: summary of the idea

propagation time
congestion
hop count
etc



before...

...after re-feedback



for another time

- deployment story
  - changes required
  - deployment incentives of different players
  - edge-to-edge re-feedback as first step
- 800-re-feedback
  - QoS for duplex connections

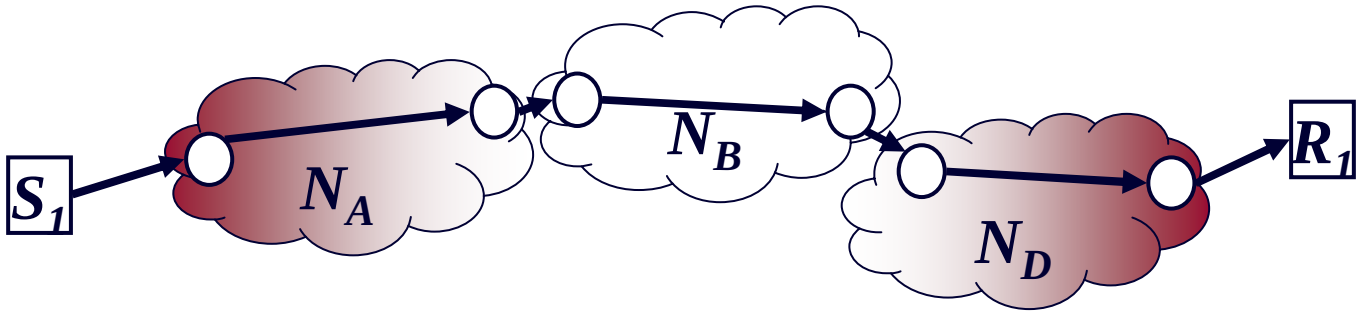
a broadband incentive solution

re-feedback

http://www.cs.ucl.ac.uk/staff/B.Briscoe/pubs.html

Q&A

path congestion typically at both edges



- congestion risk highest in access nets
  - cost economics of fan-out
- but small risk in cores/backbones
  - failures, anomalous demand

congestion competition – inter-domain routing

- if congestion → profit for a network, why not fake it?
  - upstream networks will route round more highly congested paths
  - N_A can see relative costs of paths to R_1 thru N_B & N_C
- the issue of monopoly paths
  - incentivise new provision
  - collusion issues require market regulation