ACCT: An Intelligent Congestion Control Mechanism for Future Internet

Morteza Kheirkhah
(Samsung Research UK)

Joao Reis, Fan Yang, David Griffin and Miguel Rio
(University College London)

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Motivation

- Traditional end-to-end congestion control schemes (e.g., TCP and its variants) can not meet the requirements of emerging Internet applications (e.g., VR, AR, XR, immersive media, etc.)
  - Highly diverse with conflicting requirements (High-bandwidth, low-latency, high-reliability)
- These schemes primarily design to achieve high network throughput with less regard about the end-to-end latency
- Applications with latency constraints rely on the network to meet their requirements by means of traffic engineering (segregating traffic/flows)
  - 5G network slicing, priority queue (**partially solving the problem**)

Motivation (cont.)

- The problem is aggravated over wireless networks.
  - Wireless channels fluctuate rapidly and largely, occasionally, in the order of milliseconds due to user mobility, interference from adjacent cell towers, changes in the number of active users
- Worse with emerging wireless technologies operating at high-frequency bands (e.g., mmWave and above)
  - Sensitive to the environment due to their signal propagation characteristics
- Even BBR, the state-of-art end-host-centric congestion control scheme, fails to track such capacity changes precisely

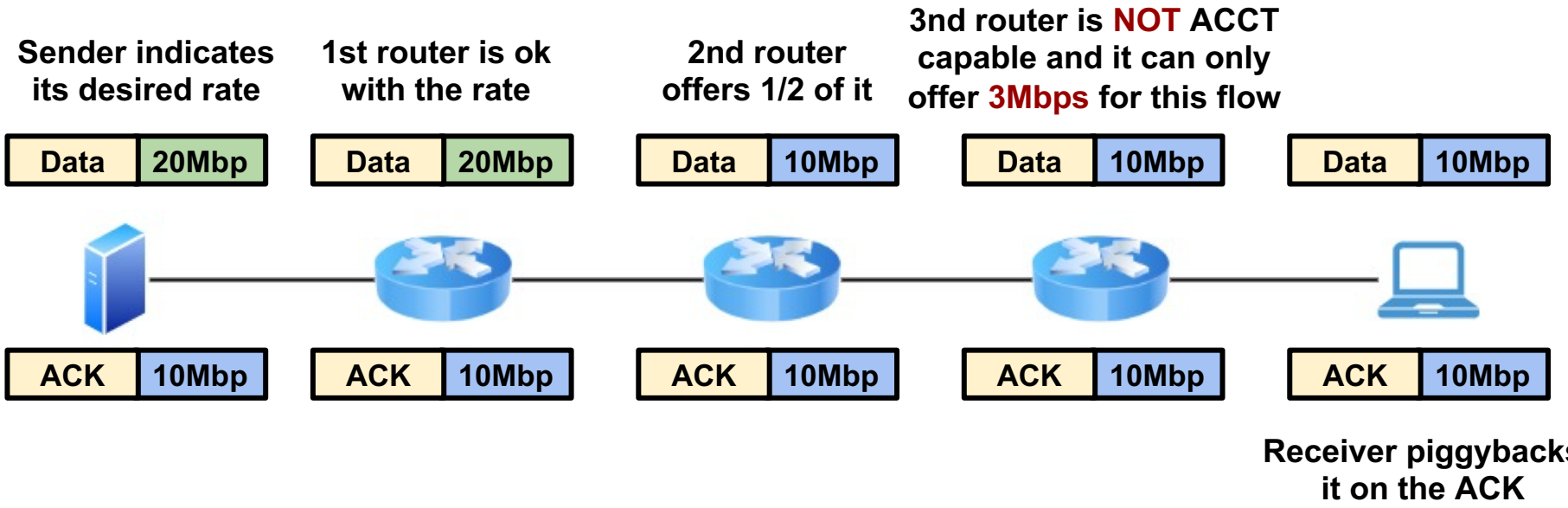
Motivation (cont.)

- A possible solution is to move towards network-centric approach (XCP, RCP)
- Each sender expresses its desired sending rate and other feedback information such as the RTT measurement to routers
- Each router along the network path provides multiple bits of feedback per packet to senders
- Senders should completely follow whatever the network says
- **Two serious problems**:
  - Does not scale well as routers need to perform complex operation per-packet
  - All network elements in all networks along the path should support the proposed signalling

ACCT

- An end-to-end, learning-based, rate control mechanism for Internet flows that is capable of considering **application** and **network** requirements simultaneously
- The ACCT sender is capable of exploiting **explicit** feedback from the network about the available capacity and also from the application about the desired sending rate
- The ACCT sender does not **blindly** adjust its sending rate to either of these signals
- ACCT designs a set of algorithms at end-hosts and routers to achieve its objectives
    - It places all complex tasks at **end-hosts**

ACCT illustration



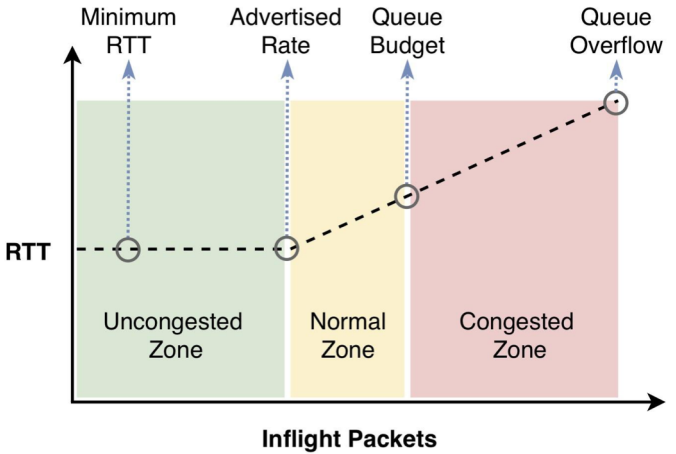
ACCT detects that the 3rd router is the bottleneck
it then regulates its sending rate on that basis

ACCT’s three main components

- **ACCT Sender.** An end-to-end congestion control algorithm that operates at the transport layer
- **ACCT RL Agent.** A RL agent that is responsible for adjusting the aggressiveness of ACCT flows at the ACCT sender’s side
- **ACCT Network Agent.** A distributed subsystem that resides at the network routers

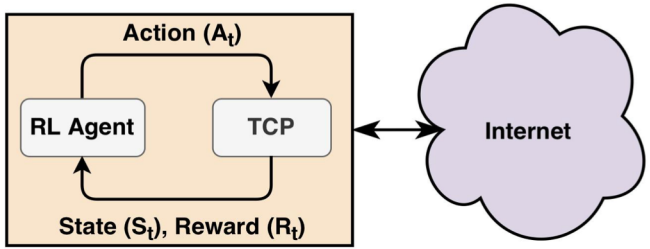
ACCT Sender

- It splits its operating zone into three distinct zones based on the explicit feedback it receives from the network and its measurements the queuing delay
- The key intuition behind this zone separation is that ACCT needs to adopt different behaviours/strategies in each zone



ACCT RL Agent

- The ACCT Sender regularly informs the RL Agent of the current operating zone (as an state input)
- In each operating zone, the ACCT Sender follows different reward functions to calculate the reward value
- The RL Agent proposes an action accordingly (which dictates the aggressiveness of the ACCT flow)



RL formulation

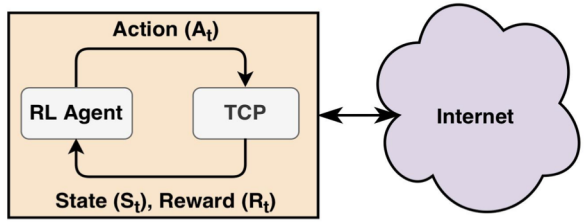
$$A_i = [1,\ 2,\ 3,\ 4,\ 5,\ 10,\ 20,\ 30,\ ...,\ 80,\ 90,\ 100]$$

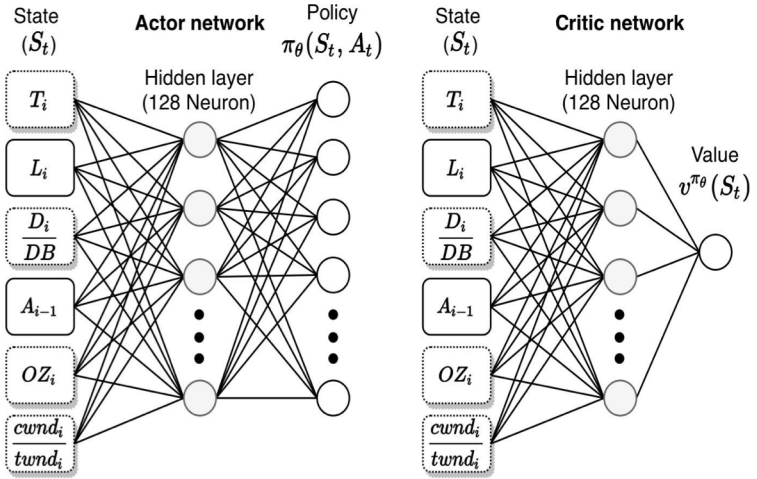
$$S_i = \{[T_i],\ L_i,\ [\frac{D_i}{DB}],\ A_{i-1},\ [Zone_i],\ [\frac{cwnd_i}{twnd_i}]\}$$

$$R_G = A_{i-1} - \omega L_i$$

$$R_Y = (as[N-1] + 1 - A_{i-1}) - \omega L_i - \zeta B_i$$

$$R_B = (as[N-1] + 1 - A_{i-1}) - \beta \frac{D_i}{DB} - \omega L_i - \zeta B_i$$





ACCT Network Agent

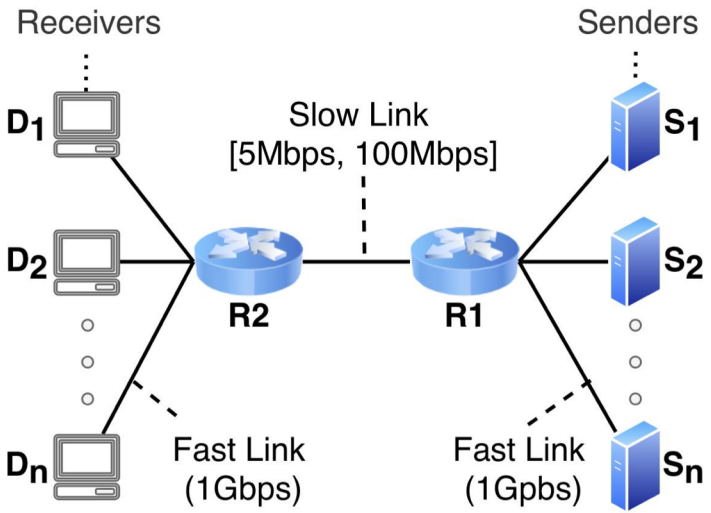
- The ACCT Network Agent follows a simple rate distribution scheme in which it distributes the available capacity across active flows
- It first estimates an equal distribution of rate between active flows
  - ES = total capacity / number of active flows
- The spare capacity of those flows with a smaller desired rate than the equal split (ES) is then allocated to flows with a higher desired rate than the ES

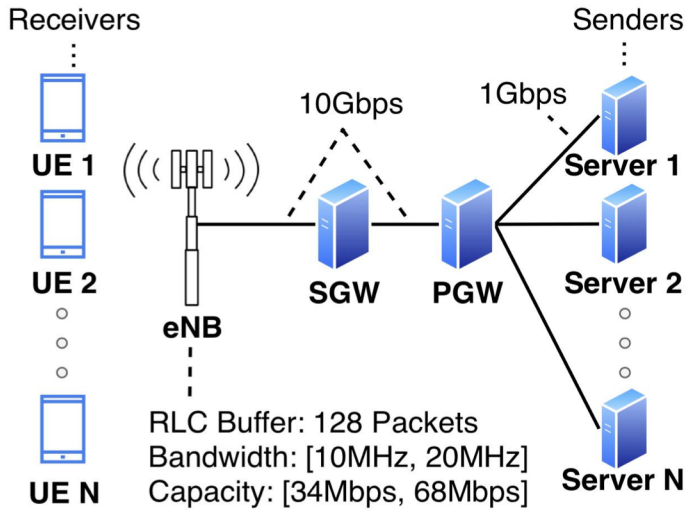
Implementation

- We implemented ACCT in NS-3 (C++)
- Our implementations support ACCT in both wired and wireless networks
- For wired networks, we modified the IP layer of the NS-3 networking stack to model ACCT-enabled routers
- For wireless networks, we modifying the PDCP and MAC layers of the LTE cellular networking stack
- We also modified the TCP modules to support ACCT signalling and implemented a new congestion control module for ACCT
- Our congestion module interacts with the ACCT RL agent via a technology agnostic protocol (Google Protocol Buffers). We wrote the RL agent (A3C) in Python

Simulation setup

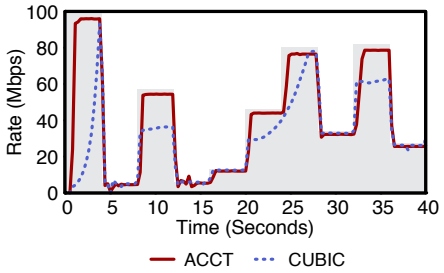
- The queueing budget is 5ms
- TCP send and receive socket buffer size was 2MB



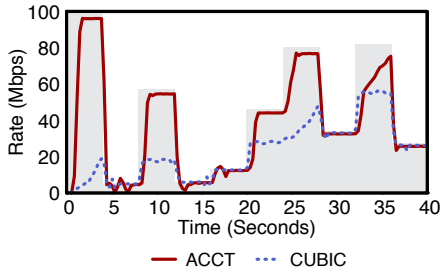


Evaluation (efficiency and responsiveness)

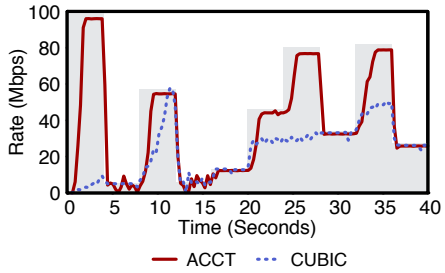
- Every 4 seconds we randomly changed the maximum capacity of the link between routers (in our wired network), ranging from 5Mbps to 100Mbps
- We turned off the slow start mechanism during the connection start-up



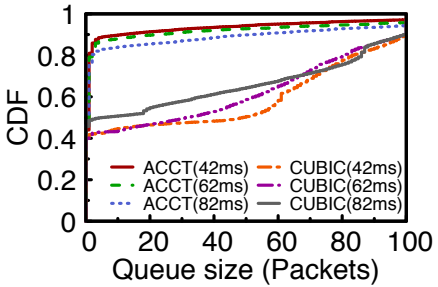
RTT: 42ms, BDP: 525KB



RTT: 62ms, BDP: 775KB

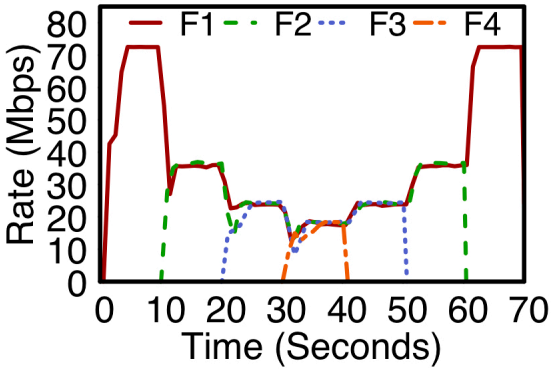


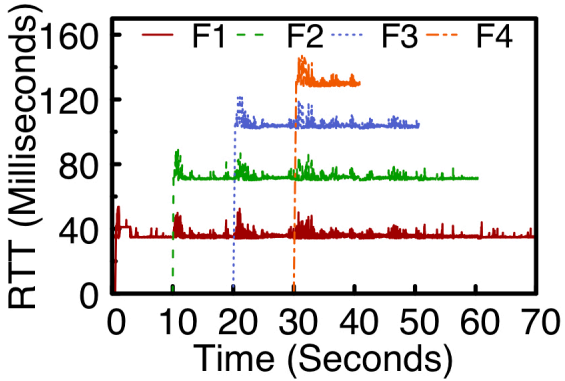
RTT: 82ms, BDP: 1MB



Evaluation (fairness)

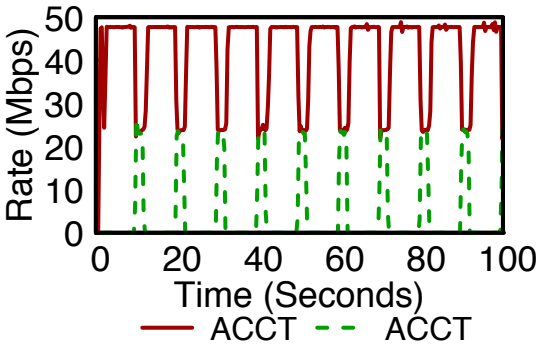
- Initially, 4 ACCT flows (each with different RTT) arrive at the UE with an inter-arrival time of 10 seconds, making the base station a bottleneck
- After 40 seconds, the flows leave the bottleneck again with 10 seconds gap between each flow's departure

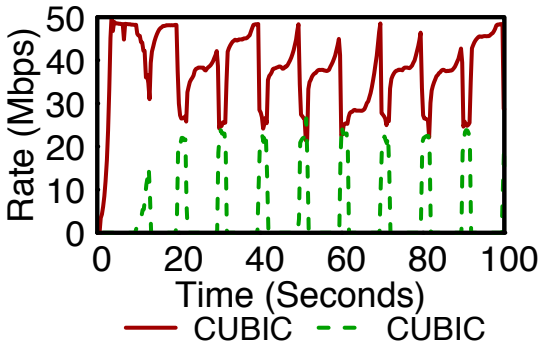


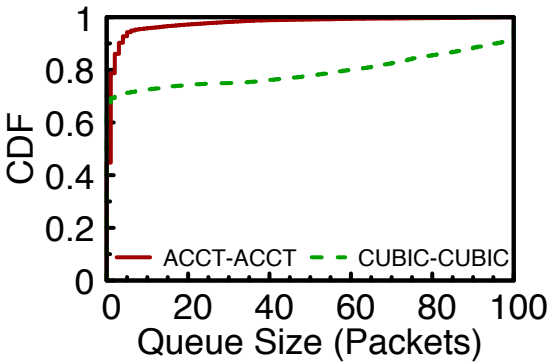


Evaluation (coexistence)

- An ACCT flow carrying file download traffic competes with another ACCT flow carrying video traffic
- Video traffic follows a ON/OFF pattern with 2-seconds ON and 8-seconds OFF

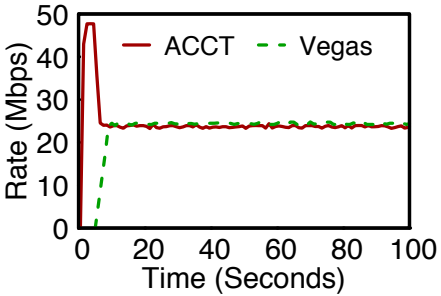


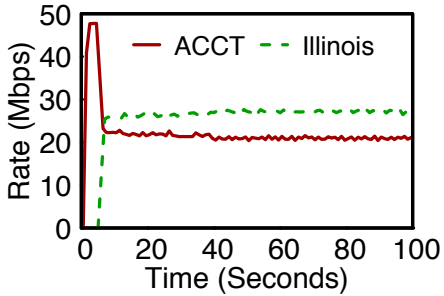


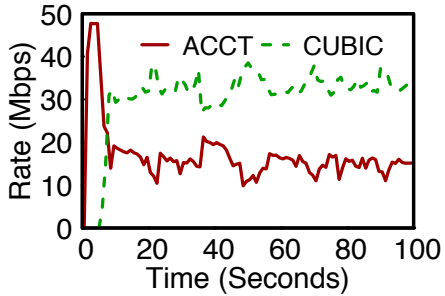


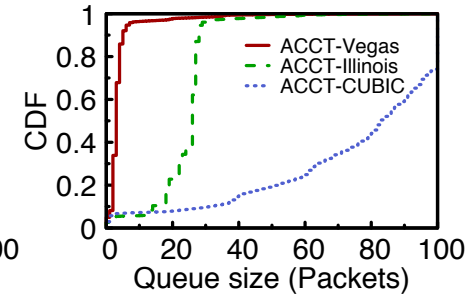
Evaluation (TCP-friendliness)

- Network fairness is preserved when ACCT competes with delayed based variants of TCP (e.g., Vegas, Illinois)
- When competing with CUBIC, it achieves its fair-share of resources but the end-to- end delay is compromised by CUBIC









Summary

- ACCT maximizes throughput and minimizes delay (within a small budget)
- ACCT converges quickly to its fair-share within an RTT
- ACCT has no bias against long RTT flows
- ACCT detects non-ACCT bottlenecks
- ACCT coexists well with non-ACCT flows

Quick links

- **Homepage**: https://www.uclmail.net/users/m.kheirkhah/
  - Everything about ACCT can be found here
- **Email**: morteza.kheirkhah@uclmail.net
  - Feel free to ask your questions
- **GitHub**: https://github.com/mkheirkhah/
  - I will add ACCT's source code here
- **LinkedIn**: https://www.linkedin.com/in/mkheirkhah/
  - Feel free to connect ☺