Steady state and transient state analyses of TCP and TCP-friendly rate control mechanism using a control theoretic approach

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Outline

- **Introduction**
  - **New transport-layer communication protocols for real-time system applications**
- **Analytic model**
  - **TFRC, TCP, RED**
- **Steady state analysis**
  - **Derive TFRC goodput, TCP goodput**
- **Transient state analysis**
  - **Use a control theoretic approach**
- **Numerical examples**
- **Conclusion**

Background

- **Real-time applications**
  - **Have been widely deployed**
  - **Use either UDP or TCP**
- **Internet**
  - **Best effort network**
    - ➢ **All network applications should have a mechanism for adapting to the congestion status of a network**

UDP (User Datagram Protocol)

- **Simple protocol for datagram transfer**
- **Doesn't have a congestion control mechanism**
- **We should implement some congestion control mechanism on application layer**

TCP (Transmission Control Protocol)

- **Has a congestion control mechanism**
  - **Adjust its packet transmission rate**
- **Designed for data transfer applications**
  - **Can tolerate a certain amount of delays**
- **AIMD window flow control**
- **Packet transmission rate fluctuates**
  - **Serious problem for a real-time applications**

New transport-layer communication protocols

- **TFRC, RAP, GAIMD**
  - TCP-Friendly Rate Control
  - Rate Adaptation Protocol
  - General AIMD Congestion Control
- **Have a congestion control mechanism**
- **Realize a fairness with competing TCP flows**
- **Change the packet transmission rate smoothly**

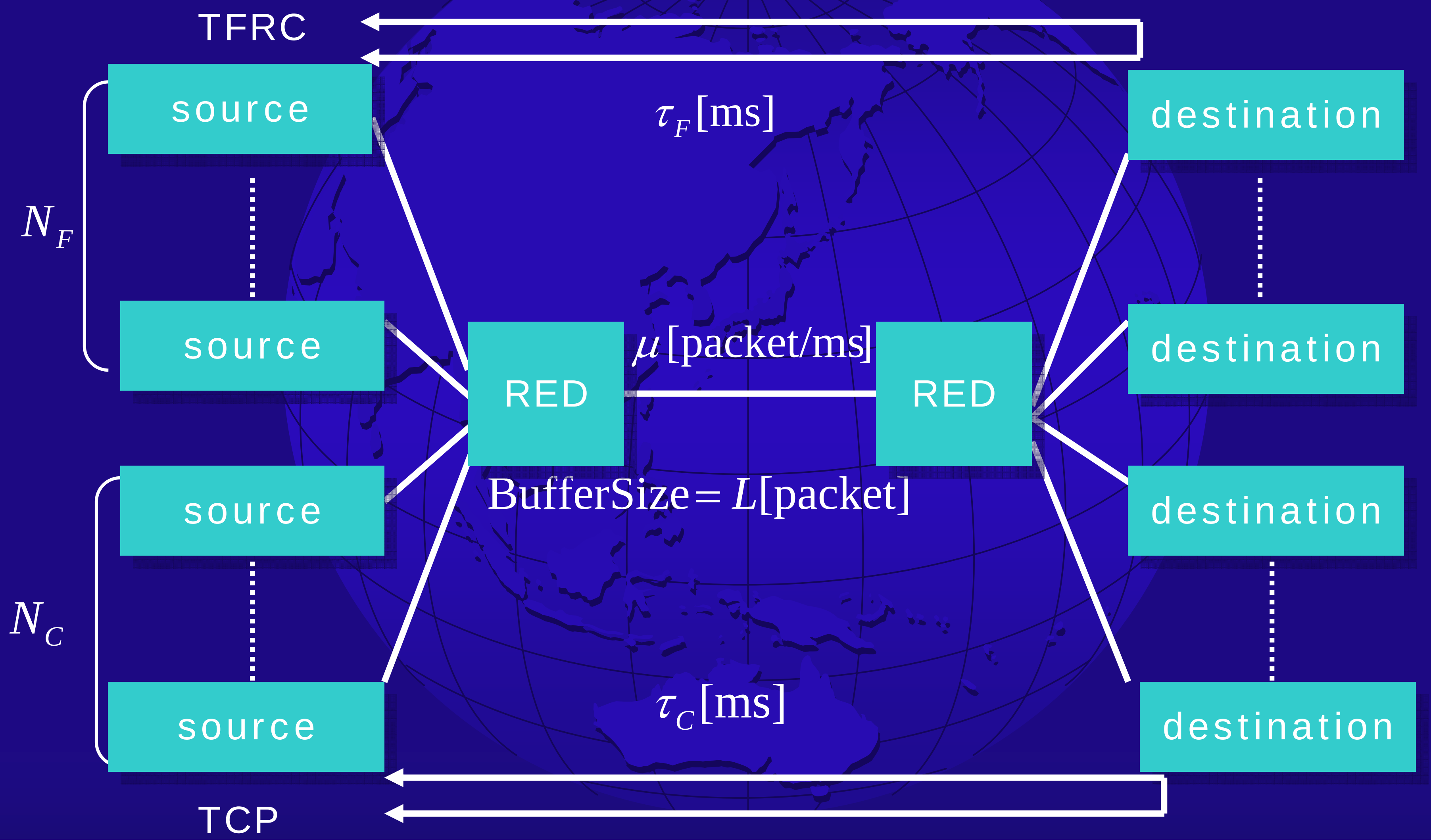
Related work

- **TFRC have been studied variously**
- **Steady state behavior**
  - **Fairness between TFRC and TCP**
  - **Validity of the rate control mechanism**
- **Transient state behavior**
  - **Smoothness of the throughput variation**
  - **Responding speed to the change of the network congestion status**
- **Most of these researches are based only on simulation experiments.**

Objectives

- Model a network with TFRC and TCP connections
  – Multiple TFRC connections
  – Multiple TCP connections
  – Single RED (Random Early Detection) router
- Steady state analysis
  – Derive several performance measures
    - TFRC goodput, TCP goodput, packet loss probability
- Transient state analysis
  – Quantitatively show convergence speed
  – Using a control theoretic approach

Analytic model



Assumption

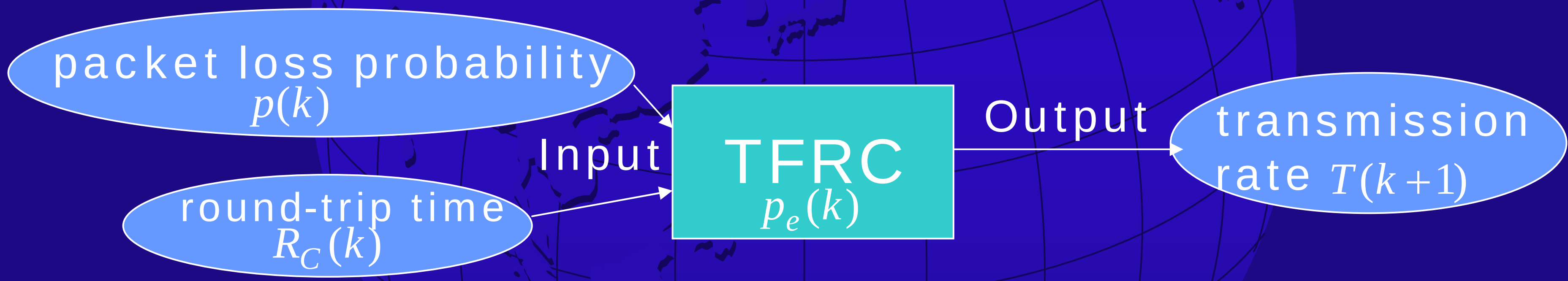
- **All TCP connections operate in their congestion avoidance phase**
- **Maximum window size of TCP is sufficiently larger than the bandwidth-delay product of a network**
- **RED routers operate appropriately**
  - **Average queue length of RED router is kept between min_{th} and max_{th}**

TFRC

- **Destination host**
  - **measures the loss event rate and feeds this information back to the source host**
    - **loss event: one or more lost packet from a window of data**
- **Source host**
  - **uses feedback messages to measure the round-trip time**
  - **Loss event rate and round-trip time are then fed into TFRC's throughput equation**
  - **adjusts its transmission rate**

Overview of model (1)

- **Model TFRC, TCP, RED as discrete time systems with a time slot of Δ**
- **TFRC**



  - **We derive packet loss event rate $p_e(k)$, as a function of packet loss probability and round-trip time**

Overview of model (2)

- **TCP**

packet loss probability $p(k)$

round-trip time $R_C(k)$

Input → TCP → Output

window size $w(k+1)$

- **RED**

TCP window size $w(k)$

TFRC transmission rate $T(k)$

Input → RED $q(k), \bar{q}(k)$ → Output

packet loss probability $p(k+1)$

TFRC & TCP round-trip time $R_C(k+1)$ & $R_F(k+1)$

$q(k)$: current queue length

$\bar{q}(k)$: average queue length

Steady state analysis

- **Obtain equilibrium values from models numerically**
  - **Equilibrium values: values in steady state**
  - **TCP window size w^*, round-trip time R_F^***
  - **TFRC transmission rate T^*, round-trip time R_C^***
  - **RED packet loss probability p^***
- **Derive TFRC & TCP goodput**
  - **TFRC goodput:** $T^* \times \left(1 - p^*\right)$
  - **TCP goodput:** $\dfrac{w^*}{R_F^*} \times \left(1 - p^*\right)$

Transient state analysis (1)

- **Define state variables & state vector**
  - **State variables:** $T(k),\cdots T\left(k-\frac{R_f(k)}{\Delta}\right), w(k),\cdots w\left(k-\frac{R_c(k)}{\Delta}\right),$
    $q(k),\cdots q\left(k-\max\left(\frac{R_f(k)}{\Delta},\frac{R_c(k)}{\Delta}\right)\right), \bar{q}(k),\cdots \bar{q}\left(k-\max\left(\frac{R_f(k)}{\Delta},\frac{R_c(k)}{\Delta}\right)\right)$
  - **State vector $x(k)$:**
    - **Differences between each state variables and its equilibrium values**

$$x(k)=(T(k)-T^*,\cdots,w(k)-w^*,q(k)-q^*,\cdots,\bar{q}(k)-\bar{q}^*)$$

Transient state analysis (2)

- **Assume TFRC notifies its source host of feedback information every M slots**
- **Linearize models around equilibrium points**
- **Obtain the transition matrix from slot k to slot $k+m$** $x(k+M) = AB^{M-1}x(k)$
  - A**: state transition matrix when TFRC source receives feedback information**
  - B**: state transition matrix when TFRC source doesn't receive feedback information**

Transient state analysis (3)

- **Eigen values of AB^{M-1} determine transient state behavior**
  - s **:the maximum absolute eigen values of AB^{M-1}, maximum modulus**
  - **smaller s: better transient behavior**
  - $s < 1$**: stable**
  - $s > 1$**: unstable**

Numerical example setting

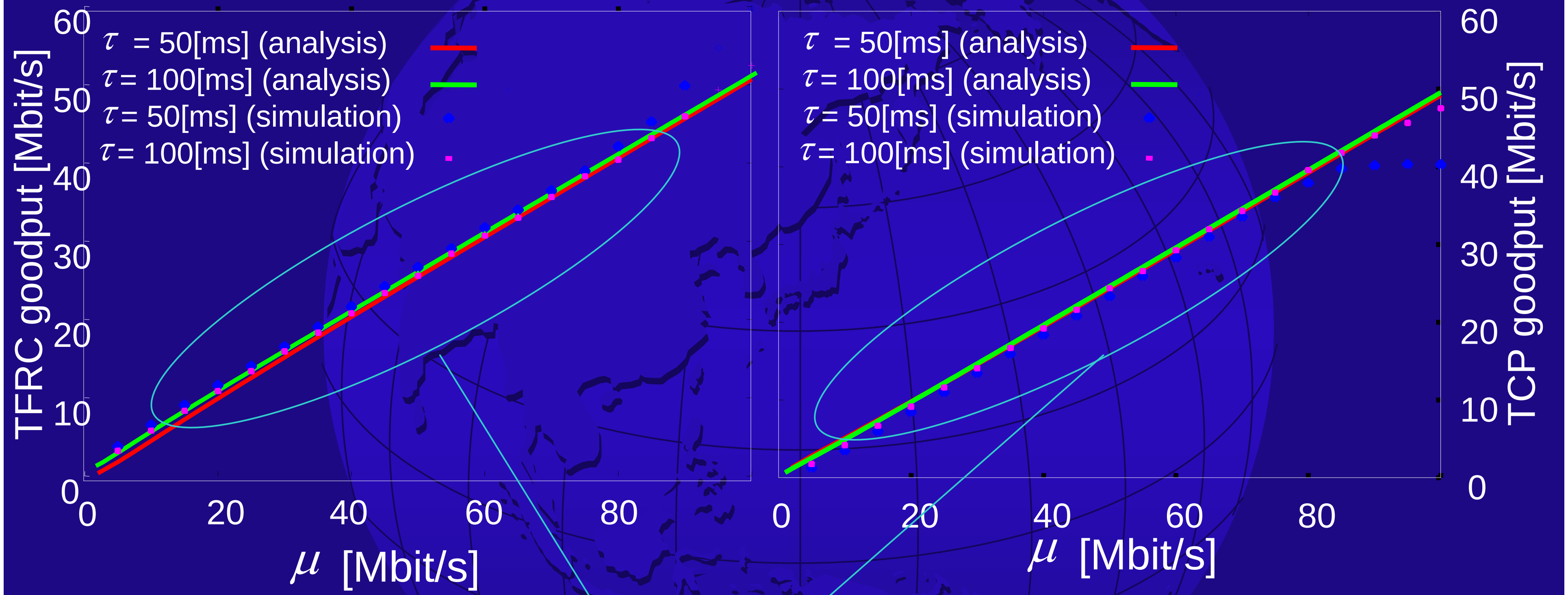
- **Analysis & simulation**
  - **TFRC & TCP packet size: 1000** [*byte*]
  - **# of TFRC & TCP connections: 10, 10**
  - **Two-way propagation delays of TFRC & TCP are set to the equal value:** $\tau_F = \tau_C = \tau [\mathrm{ms}]$
  - **RED parameters**
    - $min_{th} = 0.25\mu\tau$
    - $max_{th} = 1.25\mu\tau$
    - $L = 2.5\mu\tau$
    - $w_q = 0.002$

    $max_p = 0.1$

    L :RED buffer size [*packet*]

    μ :bottleneck link capacity [*packet/ms*]
- **Simulation**
  - **Simulator: ns-2**
  - **Simulation time: 300** [*s*]
  - **# of simulation: 10**

Numerical example



Good agreement

Conclusion

- **Analyze the steady state behavior of TFRC & TCP where TFRC & TCP coexist**
- **Model TFRC, TCP, RED as discrete time systems**
- **Derive TFRC & TCP goodput in steady state**
  - **Our analytic results show good agreement with simulation ones**
- **Analyze the transient state behavior of TFRC & TCP where TFRC & TCP coexist**

Thank you!