Active Queue Management and Scheduling in Wireless Networks: The Single Cell Case

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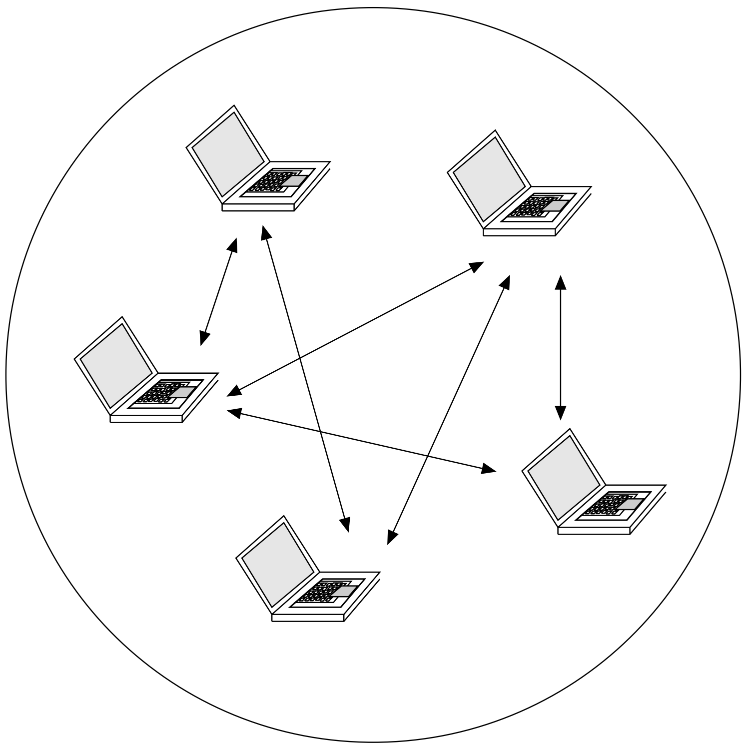
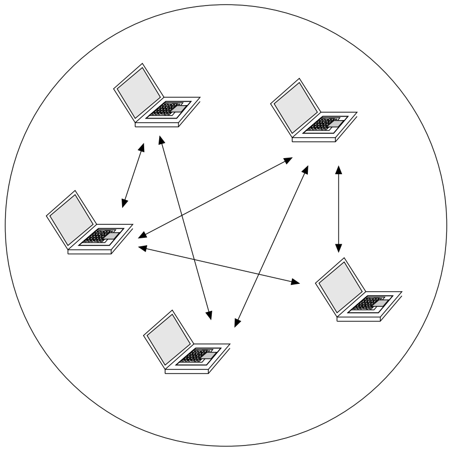
Single Cell Ad Hoc Networks



Rate and Medium Access Control



- Rate Control (TCP)
- Medium Access Control (IEEE 802.11)
- Objectives
  - Throughput
  - Fairness

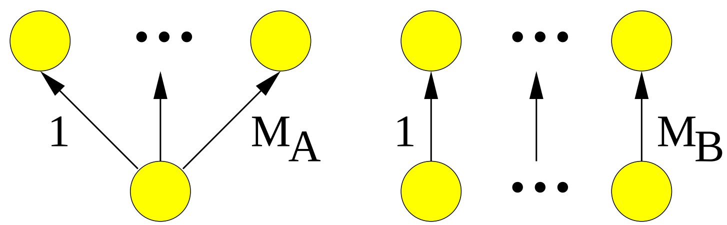
Wireline

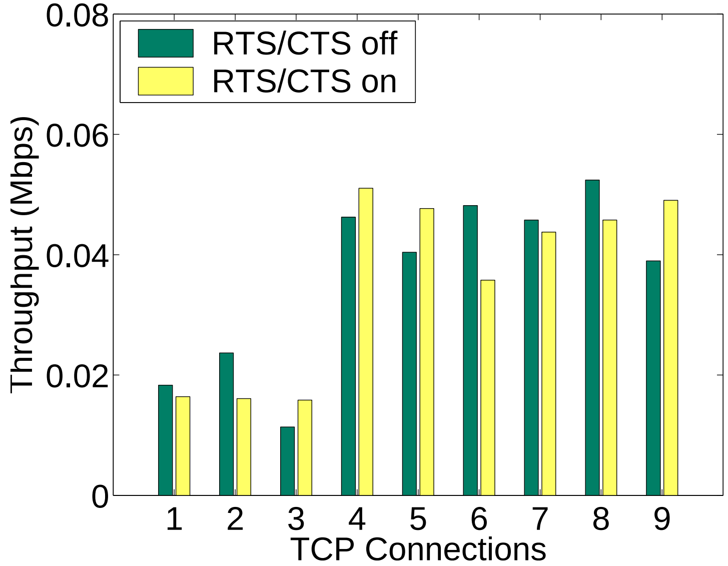
- Rate Control: TCP $->$ Stability
- AQM: RED, REM, BLUE $->$ Throughput (Operating Point)
- Scheduling: FIFO $->$ Fairness

Outline

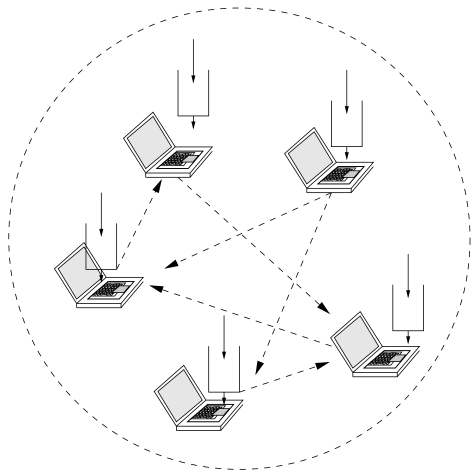
- Interaction of TCP Reno and IEEE 802.11
- Fair MAC Protocol
  - Properties
  - Centralized Solution
  - Distributed Solution
- Interaction with TCP
  - Single Cell Networks
- Discussion

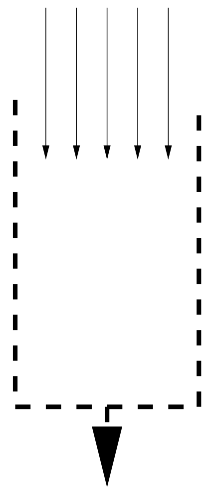
TCP Reno and IEEE 802.11: Single Cell Network





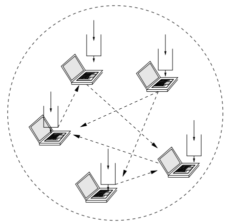
Properties of a Fair MAC Protocol

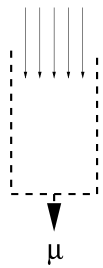




- All Packets
  - Same Delay
  - Same Drop Probability

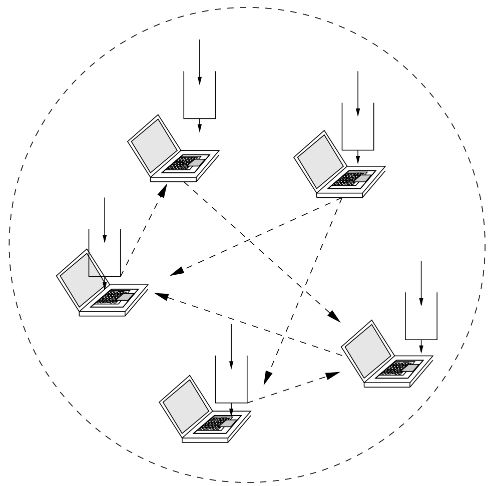
Properties of a Fair MAC Protocol





- Network Arrival Rate $\lambda = \sum \lambda_n$
- Network Throughput $X(\lambda)$
- Distributed Buffer with Service Rate μ
  - All Packets have same Delay
  - All Packet experience same Drop Probability
  - $X(\lambda)$ increasing in λ
  - $\lim_{\lambda \to \infty} X(\lambda) = \mu$

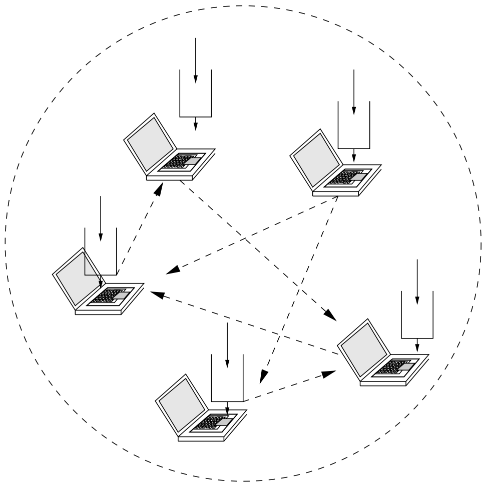
Centralized Solution



- Know Backlog b_n at each node n
- Total Backlog $B = \sum b_n$
- Schedule Node n with Probability

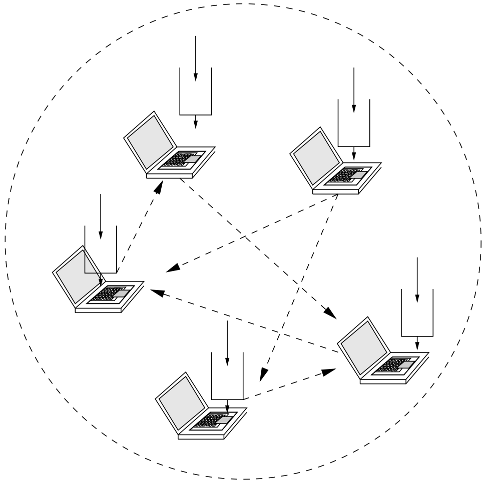
$$q_n = \frac{b_n}{B}$$

Centralized Solution



- Infinite Buffers
- Poisson Arrivals with Rate λ
- Exponential Transmission Delay with Mean $1/\mu$
- Performance as in $M/M/1$ queue

Distributed Solution



- CSMA
- Node n makes Transmission Attempt with Probability

$$q_n = \min\{b_n q, 1 - \epsilon\}$$

- CSMA with Backlog-Dependent Transmission Probabilities

Distributed Solution

- Idle Slot, L_i

$$P_i = \Pi_{n=1}^{N}(1 - qb_n) \approx \Pi_{n=1}^{N} e^{-qb_n} = e^{-qB} = e^{-G}$$

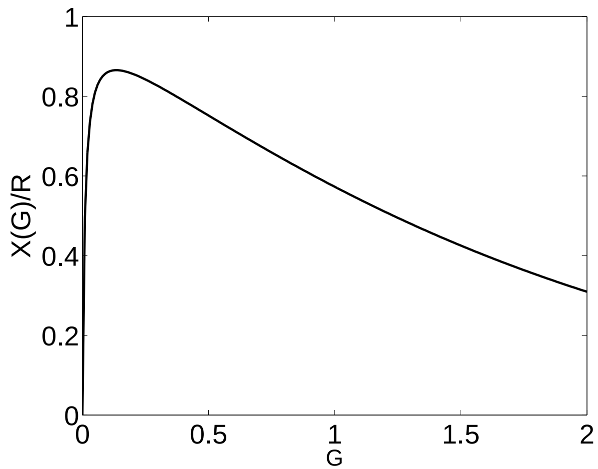
- Offered Load: $G = qB = \sum qb_n$
- Successful Transmission, L_p

$$P_s = Ge^{-G}$$

- Throughput

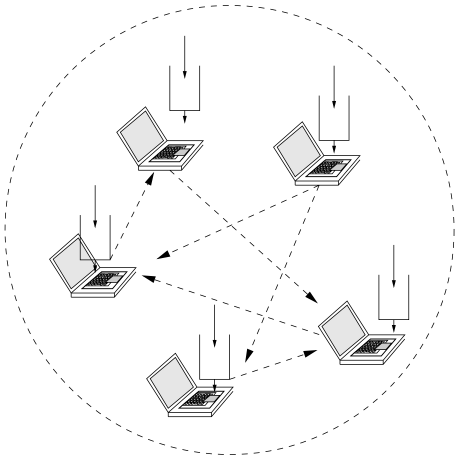
$$X(G) = \frac{Ge^{-G}}{L_i + (1 - e^{-G})L_p}$$

Distributed Solution



- Throughput $X(G) = \frac{Ge^{-G}}{L_i + (1-e^{-G})L_p}$
- $G^{+} = \sqrt{\frac{2L_i}{L_p}}$
- $G = qB = q\sum b_n$
- Active Queue Management: Keep Total Backlog at $B^{*} = G^{*}/q$

Active Queue Management



- Packet-Drop Probability $p(u)$

$$p(u) = \begin{cases} \kappa u, & 0 \leq u \leq 1/\kappa, \\ 1, & u > 1/\kappa, \end{cases}$$

- Use Channel Feedback to Compute u

Active Queue Management

- How to adapt u?
  - Idle Slot: Decrease by α
  - Busy Slot: Increase by β
- Expected Change under $G = qB$

$$\Delta u \quad = \quad -\alpha P_i + (-\alpha + \beta) P_b = -\alpha + \beta(1 - e^{-G}),$$

- Operating Point G^*: $\Delta u = 0$

$$-\alpha + \beta(1 - e^{-G^*}) = 0$$

or

$$G^* = \ln\big(\frac{\beta}{\beta - \alpha}\big)$$

Performance

- Throughput $X(G^*)$:

$$\alpha = \beta(1 - e^{-G^*})$$

- Backlog B^*

$$q = \frac{G^*}{B^*}$$

- Implements Distributed Queue with Rate $X(G^*)$

- B^* can be Chosen

Summary

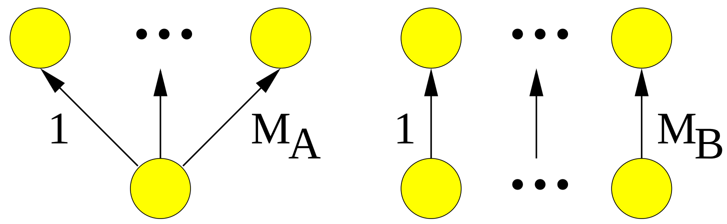
- Scheduling: CSMA with Backlog-Dependent Transmission Probabilities

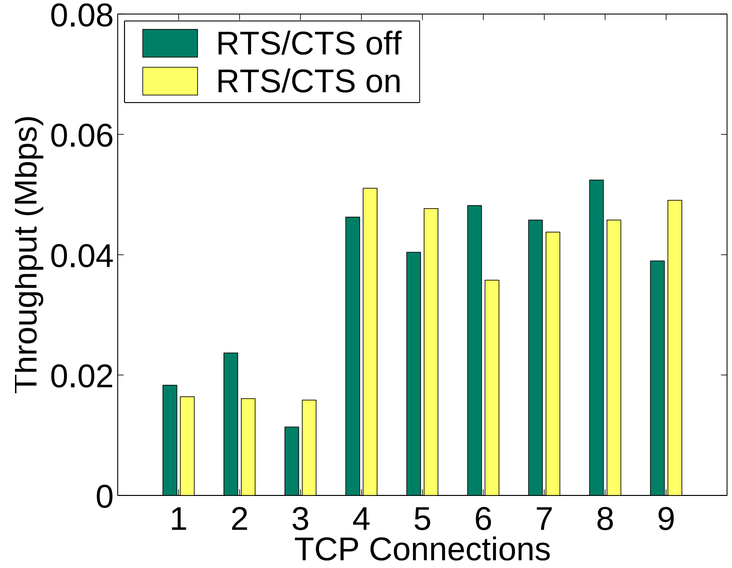
$$q_n = q b_n$$

- Active Queue Management: Drop Probability $p(u)$
  - Idle Slot: Decrease u by α
  - Busy Slot: Increase u by β
- Design of Virtual Buffer
  - Throughput $X(G^*)$
  - Buffer Size B^*

Interaction with TCP Reno: Single Cell Case

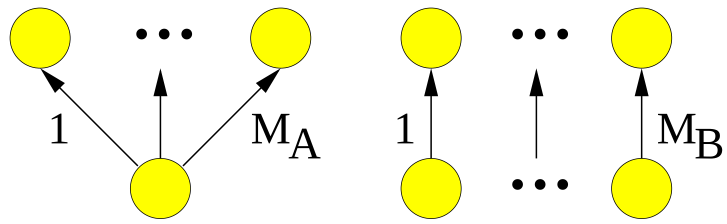
- TCP Reno and 802.11

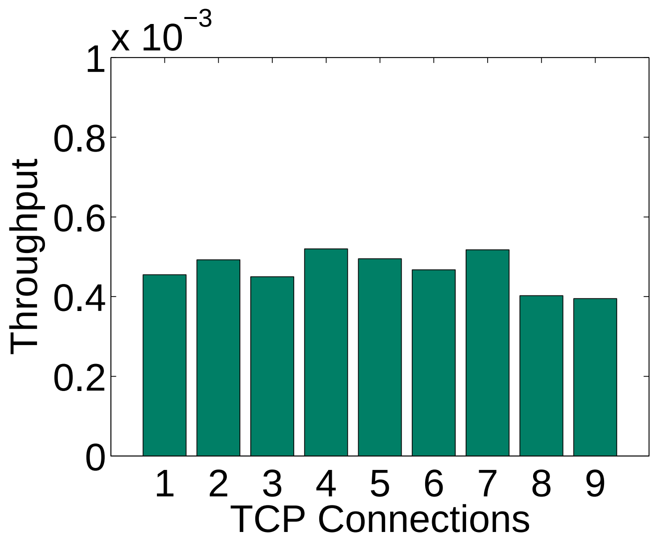




Interaction with TCP Reno: Single Cell Case

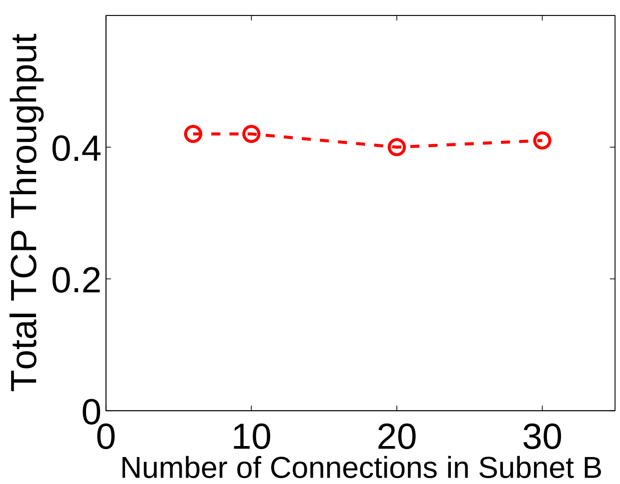
- TCP Reno and with New Mechanism

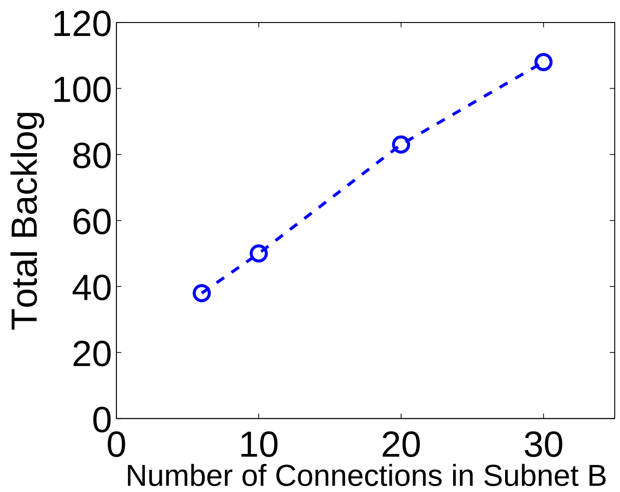




Interaction with TCP Reno: Single Cell

- Scaling as M_B increases
- $B^* = O(N)$
- $X(G^+) = 0.42$





Modelling Interaction with TCP Reno

- M Connections
- D_m: RTT of connection m
- Throughput

$$\max \sum_{m=1}^{M} \frac{\sqrt{2}}{D_m} \arctan\left(\frac{x_m D_m^2}{2}\right)$$
$$s.t. \sum_m x_m \leq X(G^*)$$
$$x_m \geq 0, m = 1, ..., M,$$

- $U_m(x_m) = \frac{\sqrt{2}}{D_m} \arctan\left(\frac{x_m D_m^2}{2}\right)$

Related Work

- AQM: RED, REM, BLUE
- NRED: RED in Wireless Networks with 802.11
- Utility Maximization
- Systematic - Practical

Conclusion

- Rate Control and MAC in Wireless Networks
- Protocol Design in Wireline Networks
- Layers
- IEEE 802.11
- Multihop Networks