Explicit and *Precise* Rate Control in Wireless Sensor Networks

Avinash Sridharan and Bhaskar Krishnamachari
University of Southern California

November 3, 2009
Introduction
An introduction to rate control.

Wireless Rate Control Protocol (WRCP)
Rate control protocol objectives

- The rate region defined by link capacity, MAC and routing.
- Rate controller moves sources from an infeasible operating point to a feasible operating point.
- Feasible point of operation defines goal of rate controller: For e.g. efficiency, fairness, etc.
Outline

Introduction
An introduction to rate control.

Wireless Rate Control Protocol (WRCP)
Why we need rate control in WSN?

- Hard to predict the capacity region of a multi-hop wireless network.
- Capacity degrades exponentially with the number of flows. For example, for 4 flows → 16 packets/sec, 20 flows → ~ 2 packets/sec, 40 flows → ~ 0.8 packets/sec.
- Given degradation in capacity with increase in number of flows, point of operation can move from feasible → infeasible region as the number of flows increase.
State of the art: AIMD-based rate control protocols

- **Convergence times** are long, since AIMD algorithms need to probe the network for capacity.
- Instantaneous queue backlogs can be large due to the probing mechanism.
Explicit and precise rate control?

- Current design of rate control protocols based on AIMD mechanism, primarily because protocols are agnostic to underlying MAC layer.
- Research in wired networks suggests, cross-layer design using explicit capacity information result in smaller flow completion times and smaller end-to-end packet delays.\(^1\)
- Can we achieve the same in WSN?

Capacity Information: 1-hop capacity of a CSMA MAC

- **Saturation Throughput:** Throughput seen by receiver, in a fully connected topology, when all senders are backlogged.

- We use saturation throughput to define 1-hop capacity of the CSMA MAC.
Receiver capacity model\(^2\)

Receiver capacity model$^2$

Receiver capacity model\textsuperscript{2}

Receiver capacity model\textsuperscript{2}

Receiver capacity model\(^2\)

Receiver capacity model

---

Introduction

Wireless Rate Control Protocol (WRCP)

Motivation, Background and Objectives

Modeling the CSMA MAC

Protocol description

Evaluation

Receiver capacity model\(^2\)

---

Receiver capacity model

Receiver capacity model\(^2\)

Constraints:

\[ r^{(2)}_{src} + r^{(3)}_{src} + 2r^{(4)}_{src} + 2r^{(5)}_{src} + r^{(6)}_{src} \leq B^{(2)} \]

Introduction

Wireless Rate Control Protocol (WRCP)

Motivation, Background and Objectives

Modeling the CSMA MAC

Protocol description

Evaluation

Receiver capacity model

Constraints:

\[ r_{src}^{(2)} + r_{src}^{(3)} + 2r_{src}^{(4)} + 2r_{src}^{(5)} + r_{src}^{(6)} \leq B^{(2)} \]

\[ r_{src}^{(2)} + r_{src}^{(3)} + r_{src}^{(4)} + r_{src}^{(5)} + 2r_{src}^{(6)} \leq B^{(3)} \]

\[ r_{src}^{(2)} + r_{src}^{(3)} + r_{src}^{(4)} + r_{src}^{(5)} + r_{src}^{(6)} \leq B^{(1)} \]

Receiver capacity model

\begin{align*}
\text{Constraints:} \\
r_{src}^{(2)} + r_{src}^{(3)} + 2r_{src}^{(4)} + 2r_{src}^{(5)} + r_{src}^{(6)} & \leq B^{(2)} \\
r_{src}^{(2)} + r_{src}^{(3)} + r_{src}^{(4)} + r_{src}^{(5)} + 2r_{src}^{(6)} & \leq B^{(3)} \\
r_{src}^{(2)} + r_{src}^{(3)} + r_{src}^{(4)} + r_{src}^{(5)} + r_{src}^{(6)} & \leq B^{(1)} \\
r_{src}^{(2)} + 2r_{src}^{(4)} + r_{src}^{(5)} & \leq B^{(4)} \\
r_{src}^{(2)} + r_{src}^{(4)} + 2r_{src}^{(5)} & \leq B^{(5)} \\
r_{src}^{(3)} + 2r_{src}^{(6)} & \leq B^{(6)}
\end{align*}

The WRCP protocol for max-min fairness

Step 1: Calculate the per-flow available capacity, $\gamma^i$, at each node $i$.

$$\gamma^i(n+1) = \frac{B^i - \sum_{j \in \text{neighbors}} p_{ji} \cdot \text{TxRate}_j^i(n)}{\sum_{j \in \text{neighbors}} p_{ji} \cdot \text{Flows}_j^i}$$

Step 2: Calculate the minimum per-flow available capacity, $\gamma^i_{min}$.

$$\gamma^i_{min}(n+1) = \min \left( \min_{j \in \text{neighbors}} \gamma^j(n), \gamma^\text{Parent}_i(n) \right)$$

Step 3: Update source rate:

$$r^i(n+1) = r^i(n) + \alpha \cdot \gamma^i_{min}(n+1)$$
WRCP is designed to work over a shortest path routing protocol such as Collection Tree Protocol (CTP), the default routing protocol for TinyOS-2.x
Experiments performed on the USC Tutorsnet testbed.
Evaluation Objectives:

- Compare WRCP’s explicit capacity mechanism against state of art distributed AIMD mechanism. We choose IFRC$^3$, Interference aware rate control protocol.
- Metric of comparison will be: Goodput and End-to-End packet delays.

$^3$Sumit Rangwala and Ramakrishna Gummadi and Ramesh Govindan and Konstantinos Psounis, Interference-Aware Fair Rate Control in Wireless Sensor Networks, SIGCOMM 2006
Static Case:

![Graph showing allocated rate over time for IFRC and WRCP sources](image-url)
Static Case: Metrics

Goodput and End-to-End packet delay

Node ID

Delay (ms)

Delay WRCP
Delay IFRC

Goodput (Pks/sec)

Goodput WRCP
Goodput IFRC

Goodput and End-to-End packet delay
Dynamic Case:

Flow activity strategy for the dynamic scenario.

Rate allocation behavior for IFRC and WRCP.
WRCP outperforms IFRC in terms of flow completion times, due to higher goodput in the dynamic flow setting.
WRCP performance under external interference

\[
\gamma^i(n + 1) = \frac{B^i - \sum_{j \in \text{neighbors}} p_{ji} \cdot TxRate^i(n) - U_i(n)}{\sum_{j \in \text{neighbors}} p_{ji} \cdot Flows^i}
\]

Generating external interference using 802.11 radios.
WRCP presents a better max-min fair solution than IFRC under external interference.
Conclusions:

- We have shown that RCM can be used for designing an explicit and precise rate control protocol.
- Our objective is not to promote max-min fairness. It is still an open question as to the type, of the utility function that protocols should be optimizing.
- We can use the RCM model to modify WRCP for other utilities as well, say proportional fairness.
- A Drawback: Needs saturation throughput information, and hence MAC specific.
Questions and code?
email: avinash.sridharan@ericsson.com

Homepage URL: http://anrg.usc.edu/~asridhar

Publication: http://anrg.usc.edu/~asridhar/papers/WRCP.pdf