Service Differentiation in 3rd Generation Mobile Networks

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Objective and approach

- Objective: Efficient resource control and service differentiation in 3G (WCDMA) networks
- Approach:

CDMA technology:
resource constraints,
user control variables that affect resource usage

+

Economic modeling:
utility functions,
congestion prices,
social welfare maximization

→ Framework for efficient resource control & service differentiation in CDMA networks

Roadmap

- Objective: Efficient resource control and service differentiation in 3G (WCDMA) networks
- Motivation
- Wireless resource constraints in uplink & downlink
- Approach based on economic modeling
  - Optimization based congestion control
- Application & numerical investigations
  - Class-based (weighted) service differentiation
- Conclusions

Motivation

for problem:

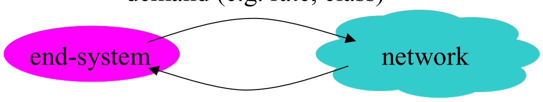
- Limited ability to increase resources of wireless networks (can't overprovision !)
- Increasing number of users accessing fixed networks through wireless

for approach:

- Successfully applied to fixed networks (IST M3I, Kelly, Gibbens et al, Key et al, Low et al, etc)
- Generalization of congestion control algorithms
- Efficient/robust resource utilization & decentralized
- Framework for seamless wired/wireless control

Congestion control and resource usage

- Closed-loop control loop



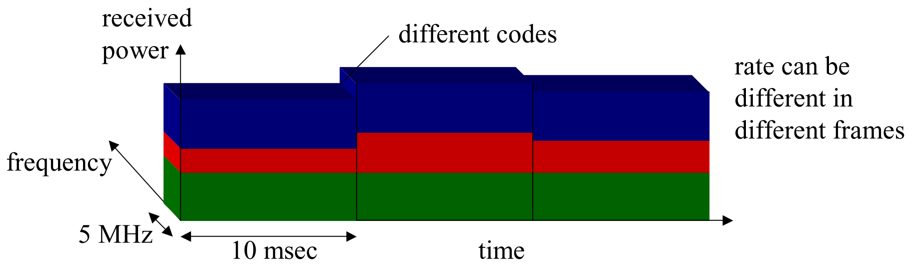
- Feedback depends on level of congestion and resource usage
- Shared resources in CDMA: radio spectrum (uplink) and base station power (downlink)
- End-system reaction to feedback modeled with utility functions

QoS & resource constraints in WCDMA

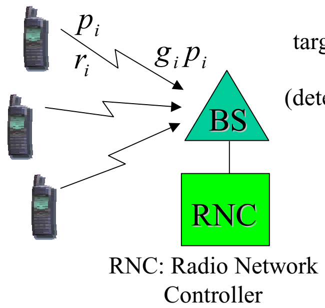
- QoS depends on two parameters, which can be different for different users
  - Transmission rate
  - Signal quality (Signal-to-Interference Ratio, SIR)
- Different resource constraints in uplink and downlink
  - Uplink constraint=total interference
    uplink resource usage=$r \cdot SIR$
  - Downlink constraint=base station power
    downlink resource usage=power

CDMA (Code Division Multiple Access)

- Wideband CDMA (WCDMA) most widely adopted 3G air interface
  - Based on Direct Sequence CDMA (DS-CDMA)
- Signals from different mobiles separated based on unique codes
- Transmission rate can change between frames



Resource usage in CDMA: Uplink



$$\underbrace{SIR_i}_{\text{target bit energy to noise density ratio } E_b/N_0 \text{ (determines bit error rate)}} = \frac{\overbrace{W}^{\text{spreading bandwidth}}}{\underbrace{r_i}_{\text{rate}}} \frac{\overbrace{g_i p_i}^{\text{received power}}}{\underbrace{\sum_{j \neq i} g_j p_j + \eta}_{\text{interference + noise}}}$$

assuming perfect power control

uplink is ***interference-limited***

resource constraint in uplink $\sum_i \frac{1}{\frac{W}{r_i SIR_i} + 1} < 1$

resource usage in uplink $\frac{1}{\frac{W}{r_i SIR_i} + 1}$

approximations for large # of mobile users

$$\sum_i r_i SIR_i < W$$

$$r_i SIR_i$$

Congestion pricing for rate-adaptive traffic

- Traffic with fixed signal quality requirements
  - SIR determines target BER
- Adaptive to rate: $U(r)$
- Charges proportional to resource usage $r \cdot SIR$
- User objective is to *maximize net utility*

$$\text{maximize} \quad U(r) - \overbrace{\lambda}^{\text{price per unit resource}} \cdot \overbrace{r \cdot SIR}^{\text{resource usage}}$$
$$\text{over} \quad r$$

Special case: logarithmic utility

- Logarithmic utility: $U_i(r_i) = w_i \log r_i$
- Weight w_i represents willingness-to-pay per unit of time

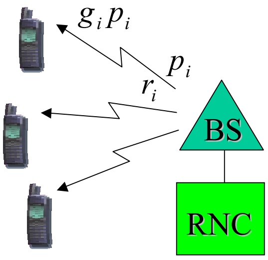
$$\frac{w_i}{r_i SIR_i} = \lambda \quad \text{(same for all users)}$$

- Rate allocation proportional to weight

$$r_i = \frac{1}{SIR_i} \frac{w_i}{\sum_j w_j} W$$

- Weight can be associated with different classes

Resource Usage in CDMA: Downlink



$$\underbrace{\overbrace{SIR_i}^{\text{target bit energy to noise density ratio } E_b/N_0 \text{ (determines bit error rate)}}}{} = \underbrace{\frac{\overbrace{W}^{\text{spreading bandwidth}}}{r_i}}_{\text{rate}} \frac{\overbrace{g_i p_i}^{\text{received power}}}{\underbrace{\theta_i g_i \sum_{j \neq i} p_j + \eta}_{\text{interference + noise}}}$$

downlink is ***power-limited***

resource constraint in downlink $\sum_i p_i < P$

resource usage in downlink p_i

Special case: logarithmic utility

- Logarithmic utility: $U_i(r_i) = w_i \log r_i$
- Weight w_i represents willingness-to-pay per unit of time

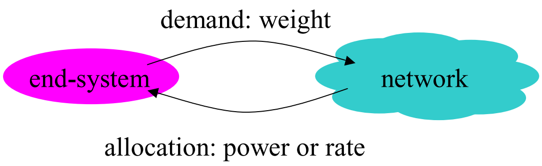
$$\frac{w_i}{p_i} = \lambda$$

(same for all users → λ)

- Power allocation proportional to weight

$$p_i = \frac{w_i}{\sum_j w_j} P$$

Application of model: two approaches



- Two approaches:
  - Allocation of power level
  - Allocation of rate
- Users can adjust weight based on their utility

Application of model: two approaches

- Direct application to power control

$$p_i = \frac{w_i}{\sum w_j} \rho P$$

  - affects fast closed-loop power control
  - results in varying signal quality

Application of model: two approaches

- Direct application to power control

$$p_i = \frac{w_i}{\sum w_j} \rho P$$

  - affects fast closed-loop power control
  - results in varying signal quality
- Estimate average power, then signal quality γ

$$\bar{p}_i = \frac{w_i}{\sum w_j} \rho P \quad r_i = \frac{W}{SIR_i} \frac{1}{\bar{l}_i \bar{I}_i} \frac{w_i}{\sum w_j} \rho P$$

  - affects load control functionality of RNC
  - power control not affected
  - weights can be associated with different classes

Case of elastic traffic

- Maximization over *two variables*: transmission rate r and signal quality SIR
- Utility for elastic traffic
  - average throughput: $r \cdot \underbrace{P_s(SIR)}_{\text{pkt success rate}}$
  - utility: $U(r \cdot P_s(SIR))$

Case of elastic traffic

- Maximization over *two variables*: transmission rate r and signal quality SIR
- Utility for elastic traffic
  - average throughput: $\underbrace{r \cdot P_s(SIR)}_{\text{pkt success rate}}$
  - utility: $U(r \cdot P_s(SIR))$
- *Proposition*: Optimal SIR^* is *independent* of *price* λ & *utility*, depends *only* on $P_s(SIR)$

$$P_s(SIR^*) = P_s'(SIR^*) \cdot SIR^*$$

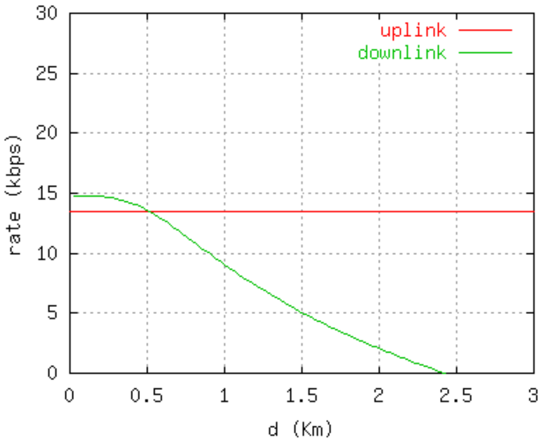
- Above allows decoupling of selection of SIR^* and r^*
  - selection of SIR^* done at CDMA layer
  - rate adaptation done at higher layer (e.g. transport)

In MOBICOM'02 paper

Numerical investigations

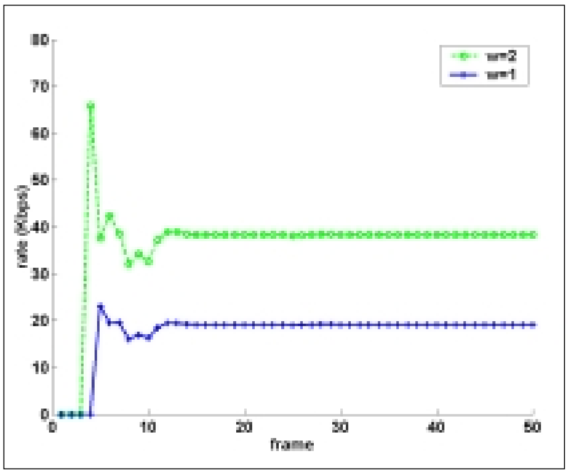
- Qualitative & quantitative
- Dependence of rate/power allocation and service differentiation on
  - uplink/downlink
  - mobile distance from base station
  - load
  - discrete rates
  - power control errors
  - SIR estimation errors

Rate allocation & distance



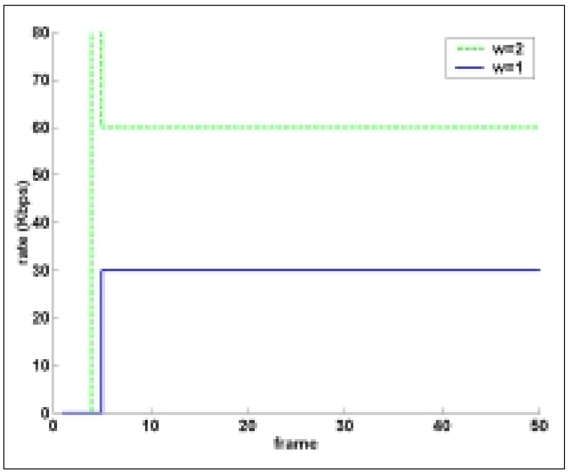
- Uplink: rate independent of mobile position
- Downlink: rate depends on mobile position

Convergence



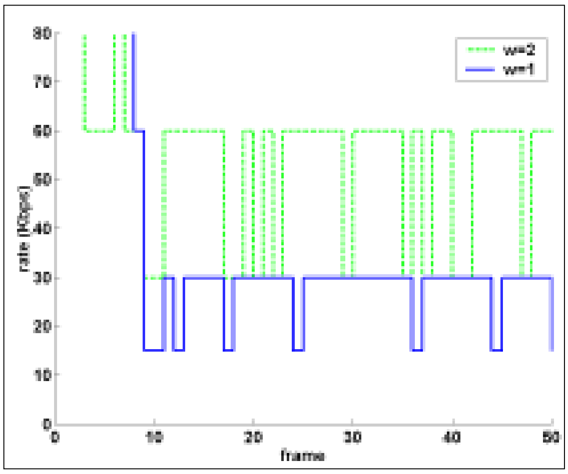
- No errors
- Convergence in a few steps

Discrete rates



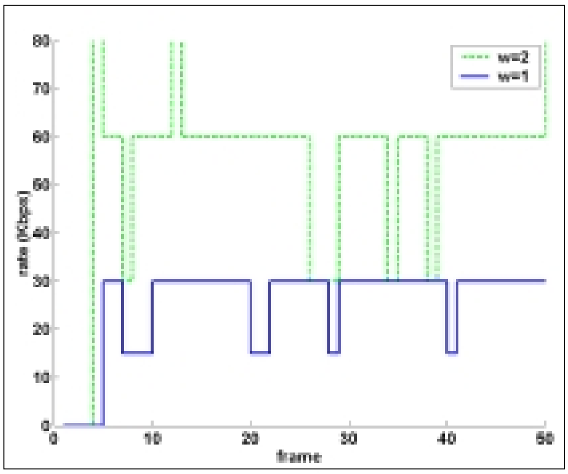
- No errors
- Convergence in a few steps
- Discrete rates

Effects of Power Control Errors



- Discrete rates
- PCE=1 dB
- Service differentiation achieved

Effects of SIR estimation errors



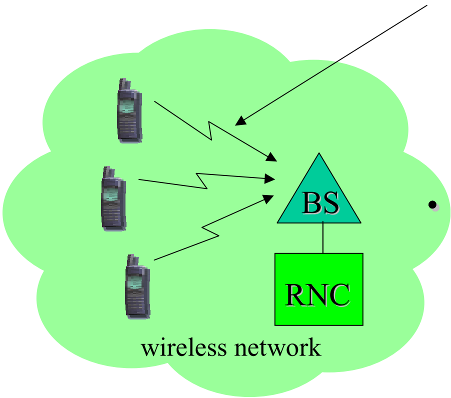
- Discrete rates
- SIRerr=1 dB
- Service differentiation achieved

Conclusions

- Application of economic modeling for
  - efficient and robust resource control,
  - service differentiation based on weights; different weights can be associated with different classes
  - taking into account wireless characteristics and resource constraints
- Related & ongoing work
  - Different forms of utility & multiple wireless hops
  - Hybrid code and time division multiplexing
  - Cell coverage (“cell breathing”)
  - Resource control in WLANs based on 802.11
  - Seamless congestion control in wireless/wired

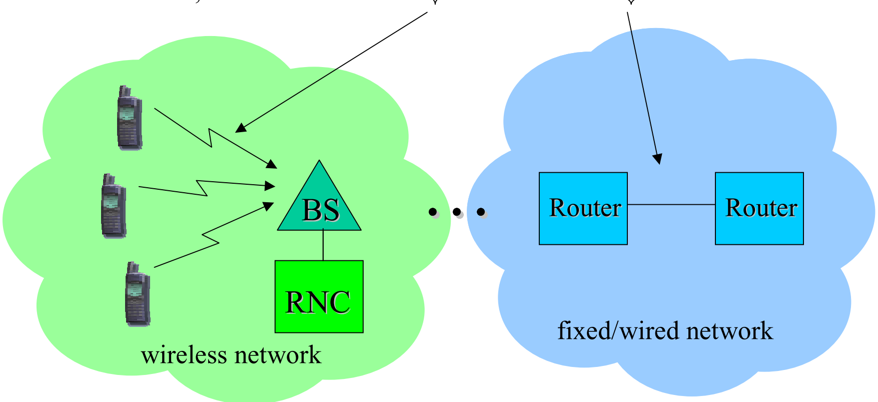
Seamless congestion control in fixed/wireless networks

$$\max_{r,SIR} \; U(\cdot) - \underbrace{\lambda \cdot r \cdot SIR}$$



Seamless congestion control in fixed/wireless networks

$$\max_{r,SIR} \; U(\cdot) - \underbrace{\lambda \cdot r \cdot SIR} - \underbrace{\mu \cdot r \cdot P_s(SIR)}$$



- ECN for common congestion signaling in wired and wireless network

Our other related publications

"Resource Control for Elastic Traffic in CDMA Networks", *ACM MobiCom 2002*, Atlanta, USA, 23-28 Sep. 2002

"Economic Models for Resource Control in Wireless Networks", *IEEE PIMRC 2002,* Lisbon, Portugal, 15-18 Sep. 2002

"Congestion Sensitive Downlink Power Control in WCDMA", *IEEE MWCN 2002,* Stockholm, Sweden, 9-11 Sep. 2002

"Cell Coverage based on Social Welfare Maximization", *IST Mobile Summit 2002*, Thessaloniki, Greece, June 2002

M4I: Joint project with BT Research (BTexact), UK

www.ics.forth.gr/netlab/wireless.html