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
  - Demand (e.g. rate, class)
  - Feedback (e.g. losses, explicit, rate)

- 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

Transmission rate can change between frames

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Resource usage in CDMA: Uplink

\[ SIR_i = \frac{g_i p_i}{\sum_{j \neq i} g_j p_j + \eta} \]

- target bit energy to noise density ratio \( E_b/N_0 \) (determines bit error rate)
- spreading bandwidth
- receiving power

assuming perfect power control

uplink is interference-limited

\[ \sum_i \frac{1}{r_i SIR_i} < 1 \]

resource constraint in uplink

\[ \frac{1}{W/r_i SIR_i} + 1 \]

resource usage in uplink

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

$$\text{maximize } \sum_{i} \left[ U(r) - \lambda \cdot r \cdot SIR \right]$$

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
  - $\frac{w_i}{r_i SIR_i} = \lambda$ same for all users
- Rate allocation proportional to weight
  - $r_i = \frac{1}{SIR_i} \sum_j w_j W$
- Weight can be associated with different classes

V. A. Siris, ICS-FORTH
Resource Usage in CDMA: Downlink

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
- Power allocation proportional to weight
  \[ p_i = \sum_j \frac{w_j}{P} \]
Application of model: two approaches

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

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
  
  \[ \bar{p}_i = \frac{w_i}{\sum w_j} \rho P \quad r_i = \frac{W}{SIR_i \bar{I}_i} \frac{1}{\sum w_j} \rho P \]
  
  - 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: \( r \cdot P_s(SIR) \)
  - utility: \( U(r \cdot P_s(SIR)) \) pkt success rate
Case of elastic traffic

- Maximization over two variables: transmission rate \( r \) and signal quality \( SIR \)
- Utility for elastic traffic
  - average throughput: \( r \cdot P_s(SIR) \)
  - utility: \( U(r \cdot P_s(SIR)) \) pkt success rate
- Proposition: Optimal \( SIR^* \) is independent of price \( \lambda \) & 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

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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

\[
\max_{r, SIR} \ U(r) - \lambda \cdot r \cdot SIR
\]

- 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”,

“Congestion Sensitive Downlink Power Control in WCDMA”,

“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