Adaptive QoS Control by Toggling Voice Traffic between Circuit and Packet Cellular Networks

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Motivations

A physical channel

PSTN phone

cell

BTS

BTS
Motivations
Goals

- Bandwidth Adaptation without Radio Access Network Modification for easy deployment
Hybrid Cellular Network

- **Circuit-switched Cellular Network**
  - A channel is dedicated to an active mobile station.
  - Good for voice traffic transportation

- **Packet-switched Cellular Network**
  - Several MSs are multiplexed onto a single physical channel.
  - Has an increased channel utilization
  - Good for bursty data traffic

- Circuit-switching will not disappear for the foreseeable future due to its wide deployment and reliable voice transportation.

- **Hybrid cellular network** (GSM/GPRS cellular network)
Channel Scheduling in GSM/GPRS network

GSM

GPRS

GPRS

2 logical channels / 1 physical channel

BTS

cell
## Circuit or Packet for Voice traffic

<table>
<thead>
<tr>
<th></th>
<th>Circuit-switched call (GSM)</th>
<th>Packet-switched call (VoIP over GPRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources (wireless channels)</td>
<td>Dedicated</td>
<td>Shared</td>
</tr>
<tr>
<td>Bandwidth requirement</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(codec, silence suppression, Comfort-Noise-Generation )</td>
</tr>
<tr>
<td>Call quality</td>
<td>Good</td>
<td>Bad</td>
</tr>
<tr>
<td>Call block rate &amp; Call drop rate</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Billing</td>
<td>Call Length</td>
<td>Amount of data sent and received</td>
</tr>
<tr>
<td>Charge/Time</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Suitable in</td>
<td>Non-overloaded cells</td>
<td>Overloaded cells (e.g. emergency area)</td>
</tr>
<tr>
<td>Advantage</td>
<td>Provide quality calls</td>
<td>Admit more calls</td>
</tr>
</tbody>
</table>
Applications

- **User-driven QoS control**
  - Mobile users can toggle in favor of call quality or billing in the middle of a call.

- **Network-driven QoS control**
  - Toggling can be used as a bandwidth adaptation scheme that deals with cell overloading
    - when a cell is under-loaded
      - network initiates as many quality circuit-switched calls as possible
      - network toggles some of the ongoing packet-switched calls into circuit-switched calls
    - when a cell is over-loaded
      - network initiates as many bandwidth-efficient packet-switched calls as possible
      - network toggles some of the ongoing circuit-switched calls into packet-switched calls
Challenges

- Seamless toggling between circuit and packet-switched networks
  - Transparent to User
  - Small Toggling Delay
- No bandwidth overhead
- Minimum Radio Access Network Modification (for easy deployment)
- Implemented as an add-on feature
  - Mobile stations not conforming to our scheme can bypass the add-on feature and still be compatible with our proposed framework
Agenda

- Motivation & Goals
- Voice over GPRS
- Proposed Schemes
  - Promotion/Demotion
  - 3 bandwidth adaptive toggle schemes
  - whom to pro/demote
- Experiments
- Implementation Scenarios
- Conclusion & Future Work
General Packet Radio Service

- Overlay network on GSM cellular network
- Applies a packet radio principle to transfer user data packets between MS and BTS → Instant IP access
- Backbone network is based on the Internet Protocol (IP)
- Shorter access times & high data rates
  - below 1 second << several seconds in GSM
  - 9.05k(CS-1), 13.4k(CS-2), 15.6k(CS-3), 21.4k(CS-4) / physical channel
- Billing is based on the amount of data sent and received
Internetworking among GPRS, GSM, PSTN, and IP network

- 4 possible connections: GSM-PSTN, GSM-IP, GPRS-PSTN, GPRS-IP
How many VoIP calls are possible?

The packet size of a frame before RLP/MAC layer

- **5.3 kbps**
  - G.723.1 codec (5.3 kbps version) generates 20-octet frames every 30ms

- **19.2 kbps**
  - SNDCP(5)/LLC(7)/RTP(12)/UDP(8)/IP(20) headers are added

- **9.6 kbps**
  - RTP/UDP/IP header can be compressed into 4 bytes [36 bytes every 30 ms

**Voice Activity Detection (VAD) discards**
35-50 percent silence

**4.8 ~ 6.24 kbps** (long-term bandwidth requirement)

**2 VoIP calls** *per CS-2 packet data channel!**
Example (5 physical channels)

- 5 circuit-switched channels in a cell
  - 5 GSM calls at most = 5 logical channels

- 3 circuit-switched channels + 2 packet-switched channels
  - 3 GSM calls + 4 VoIP calls = 7 logical channels
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Promotion & Demotion

- Promotion: VoIP (packet) -> GSM (circuit)
- Demotion: GSM (circuit) -> VoIP (packet)
Mobile Station States

- **Network mode**
  - Pro/demotion are driven by the base station controller based on some criteria.

- **User mode**
  - Keep the current mode until the users explicitly demote or promote their calls or switch to the network mode.
  - User-executed pro/demotions are given higher priorities.

[Diagram showing state transitions between Network mode (promoted/demoted) and User mode (promoted/demoted).]
Pro/demotion by 3-way calling

3-way calling: network primitive for switching between CS and PS
3-way calling

Class-A GPRS phone
3 Bandwidth Adaptive Toggle Schemes

- Circuit-based scheme
- Packet-based scheme
- Hybrid scheme
Scheme 1: Circuit-based Scheme

Demotion in circuit-based scheme
Scheme 2: Packet-based Scheme

Promotion by 3-way calling

Promotion in circuit-based scheme
Scheme 3: Hybrid Scheme

- A new call is made from either from circuit or packet mode depending on the cell status
  - When a cell is not overloaded
    • A new call is initiated as a GSM call
    • This GSM call is *non-demoteable* call
  - When a cell is overloaded
    • A new call is initiated as a VoIP call
    • This VoIP call can be promoted or demoted later
- The packet-based scheme is enabled when
  - channel usage indicator > *VoIP Trigger Threshold*
- These switch-able calls can alleviate the cell overloading
Agenda

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- Experiments
- Implementation Scenario
- Conclusion & Future Work
3 Criteria

- Cumulative Mean Opinion Score (MOS)
- Hiccups
- Call Duration
Cumulative MOS

- Standardized ranking system for measuring call quality
- Mean Opinion Score
  - 5-point (from excellent(5) to bad(1))
  - GSM (Enhanced Full Rate) : 4.0
  - VoIP (G.723.1 with 3% frame loss rate) : 3.4

\[
CMV = \left( \frac{(MOS_{\text{circuit}} \cdot D_i) + (MOS_{\text{packet}} \cdot D_j)}{D} \right) / D
\]

\[
(4 \times 5 + 3.4 \times 3 + 4 \times 2) / 10 = 3.82 \text{ (MOS)}
\]

\[
(4 \times 3 + 3.4 \times 5 + 4 \times 2) / 10 = 3.7 \text{ (MOS)}
\]

call A

call B

A handoff or new call started

demotion triggered (current)

demoted !!
Hiccups

- When demotion or promotion is performed, users may experience hiccups or delays
- The number of hiccups should be minimized and at the same time they should be distributed evenly throughout the call

![Diagram showing call A and call B with hiccups and demotion]

- **GSM**: Blue
- **VoIP**: Yellow

A handoff or new call started

Demotion triggered (current)

Demoted!!
Hiccups (con’t)

A handoff or new call started

demotion triggered (current)

call A

1 1 5 1 1 1

call B

1 1 5 1 1

demoted !!

GSM

VoIP
Hiccups (con’t)

- \( CHV = 1 / (A_0/T_0 + \square (A/T_i)) \)
  - \( A_0 \): a weight value for call start or handoff
  - \( A \): \( A_p \) (a weight value for promotion) or \( A_d \) (for demotion)
    - \( A_p \square A_d \): circuit-based scheme
    - \( A_p \gg A_d \): packet-based and hybrid scheme

![Diagram showing call A with T0, T1, T2, and Tm, indicating a handoff or new call started and demotion triggered (current).]
Call duration in a cell

- Why call duration?
  - It is not desirable to demote or promote the calls that have been initiated or handoff-ed recently
  - It is not desirable to demote or promote the calls which will handoff soon (calls of fast moving users)
  - Above two kinds of calls have small call duration in the current cell

- CDV = D
  - D indicates the duration of a call after it is initiated in or handoff-ed to the current cell
  - Demote the call whose CDV is larger
Utility Function

- Two Utility Functions
  - Combined Utility
    - $Utility_i = a \cdot CMV_i + b \cdot CHV_i + c \cdot CDV_i$
    - $a$, $b$, and $c$ are weight values and configured by the base station controller
  - Prioritized Utility
    - $Utility_i = Priority(Permuted(CMV_i, CHV_i, CDV_i))$
    - Each cell can have a different $Permute$ function
    - $Priority$ functions as a tie breaker

- Demote the candidate call with a large utility value
- Promote the candidate call with a small utility value
Experiment Scenarios

- **Targets**
  - Call Block Rate, Call Drop Rate
  - VoIP duration, number of promotions & demotions per call
  - Revenue

- **Combinations of simulations**
  - circuit-based, packet-based, and hybrid schemes
  - free users vs. restricted users (under Intersection topology)
  - premium users vs. normal users
  - different maximum VoIP channel ratios (MVCR)
  - different VoIP trigger thresholds (for hybrid scheme)

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![Plain](image1.png) ![Intersection](image2.png)

Plain  Intersection
Simulation parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>8 X 8 cells</td>
</tr>
<tr>
<td>Network Topology</td>
<td>plain, intersection</td>
</tr>
<tr>
<td>Traffic Channels per Cell</td>
<td>50</td>
</tr>
<tr>
<td>VoIP calls per physical channel</td>
<td>2</td>
</tr>
<tr>
<td>Number of Mobile Stations</td>
<td>1000..7000</td>
</tr>
<tr>
<td>Mobile Station Movement</td>
<td>directed</td>
</tr>
<tr>
<td>Average Call Length (exponential)</td>
<td>180 sec</td>
</tr>
<tr>
<td>Average Idle Time (exponential)</td>
<td>100 sec</td>
</tr>
<tr>
<td>Mean Cell Residence Time (exponential)</td>
<td>90 sec</td>
</tr>
<tr>
<td>Grace Period for Demotion</td>
<td>5 sec</td>
</tr>
<tr>
<td>Maximum VoIP Channel Ratio (MVCR)</td>
<td>0.1..0.5</td>
</tr>
<tr>
<td>Upper Watermark Point (in ratio)</td>
<td>0.8</td>
</tr>
<tr>
<td>Upper Guard Point (in ratio)</td>
<td>0.75</td>
</tr>
<tr>
<td>Lower Guard Point (in ratio)</td>
<td>0.55</td>
</tr>
<tr>
<td>Lower Watermark Point (in ratio)</td>
<td>0.5</td>
</tr>
<tr>
<td>VoIP Trigger Threshold (in ratio)</td>
<td>0.5</td>
</tr>
<tr>
<td>Utility Function</td>
<td>Combined Utility with a=1, b=0, c=0</td>
</tr>
</tbody>
</table>


Number of Promotions per Call

- A large VoIP trigger threshold makes the hybrid scheme behave like the circuit-based scheme.
Revenue

- Only cumulative MOS is considered for revenue
- Hybrid scheme triggers VoIP for new calls too early
Conclusion

- Hybrid scheme works best
- Provides a seamless toggling between circuit and packet cellular networks

“Easy to deploy” QoS Control
The End

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