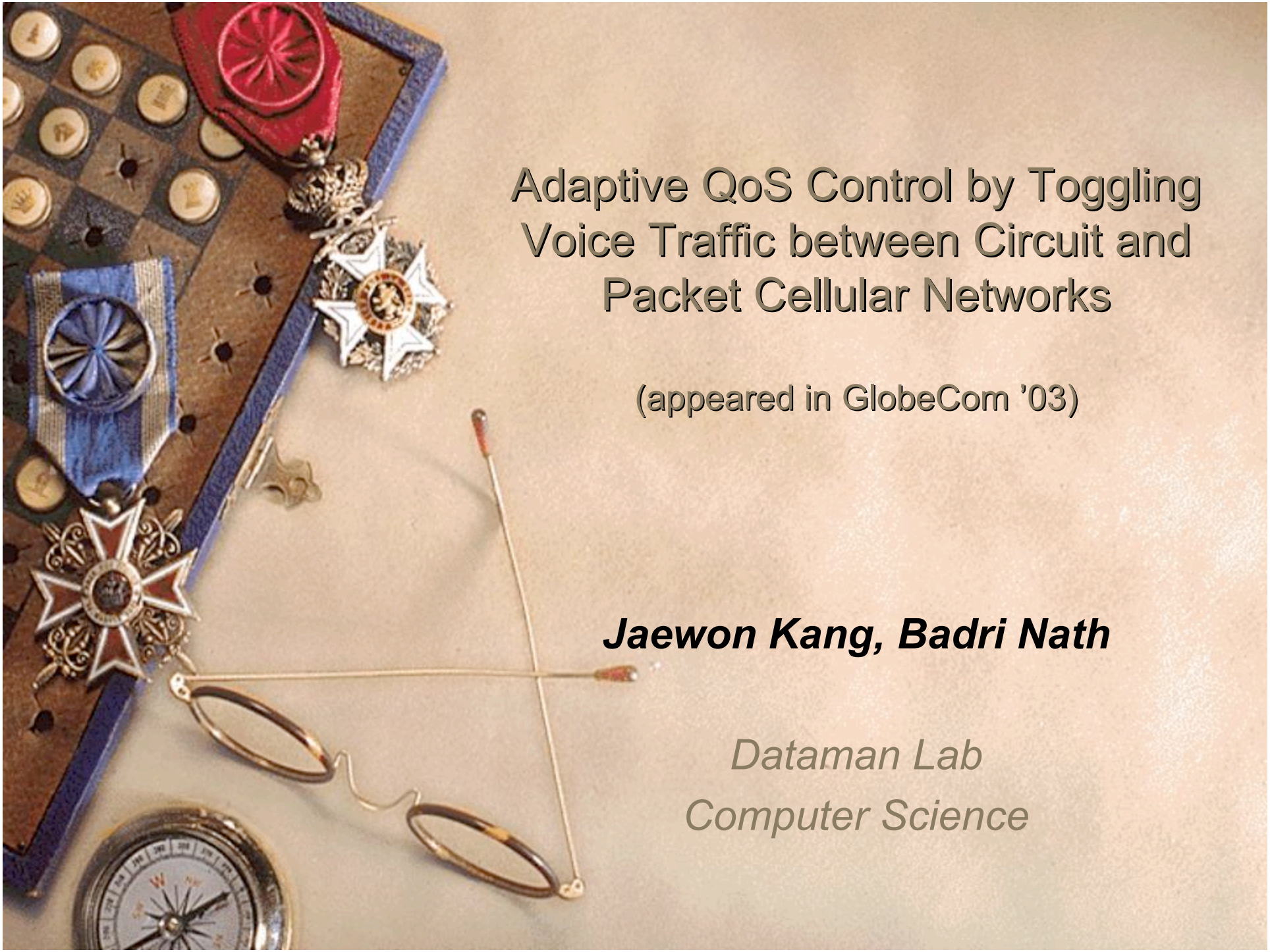

Adaptive QoS Control by Toggling Voice Traffic between Circuit and Packet Cellular Networks

(appeared in GlobeCom '03)

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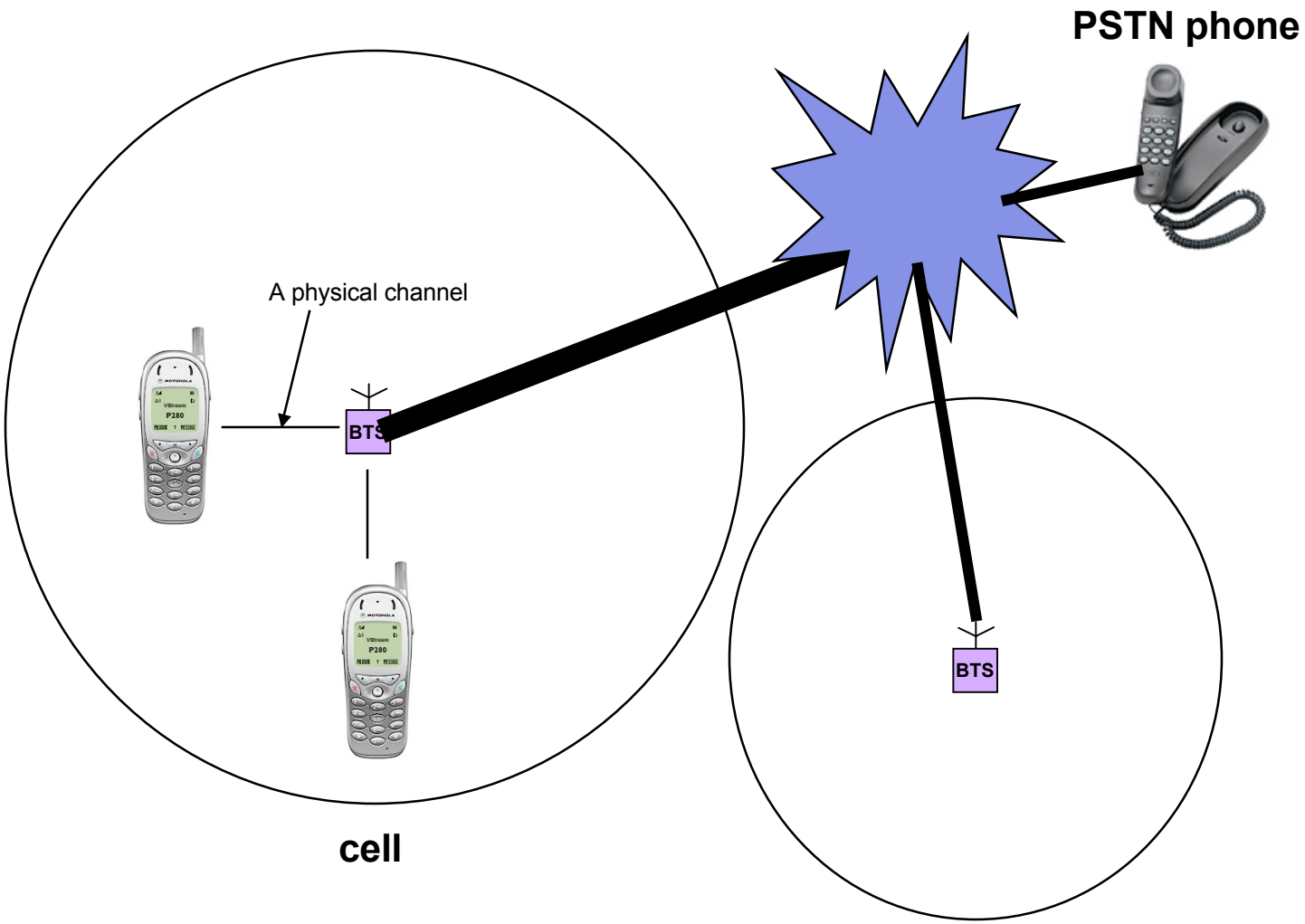
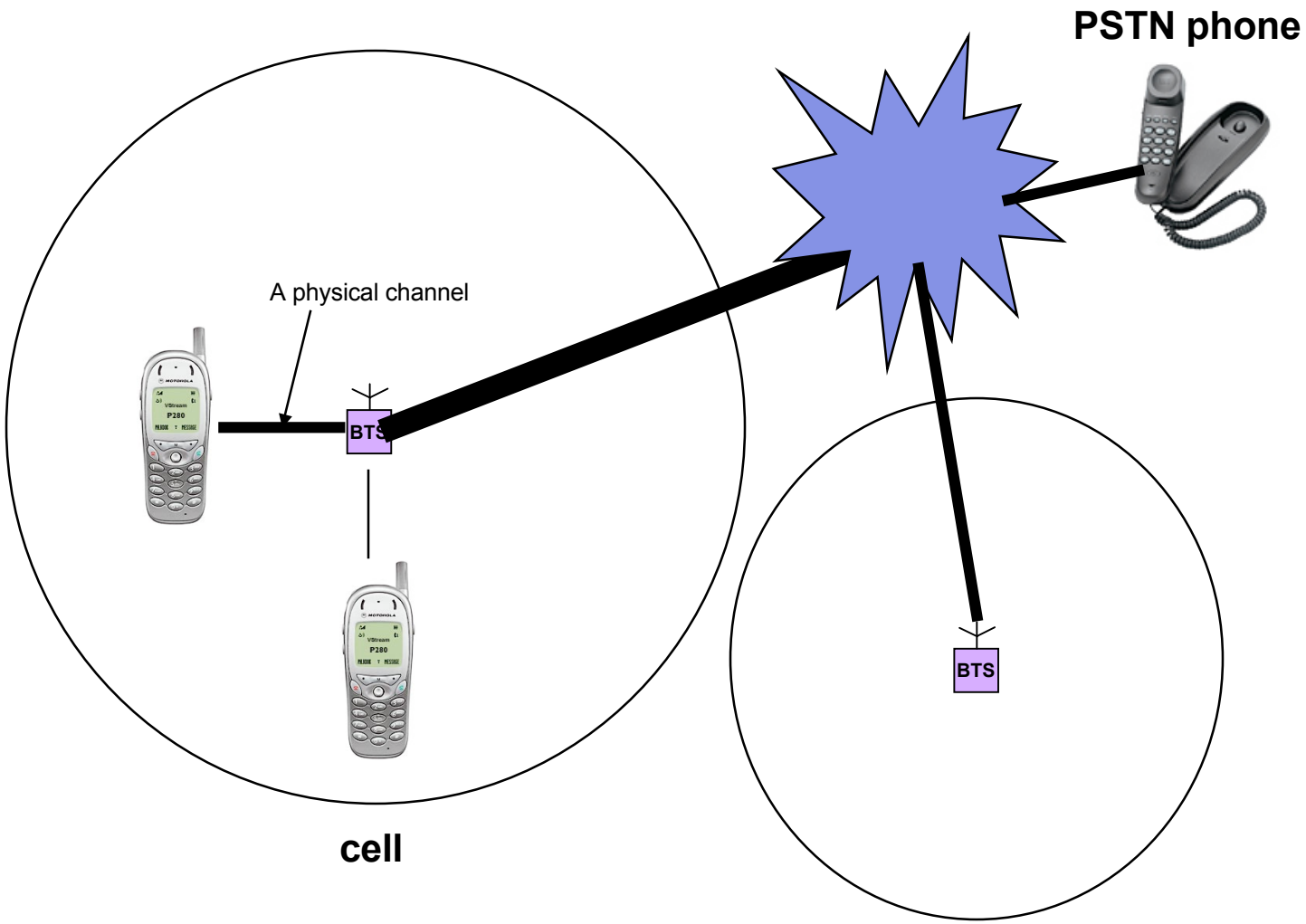
Motivations



Motivations



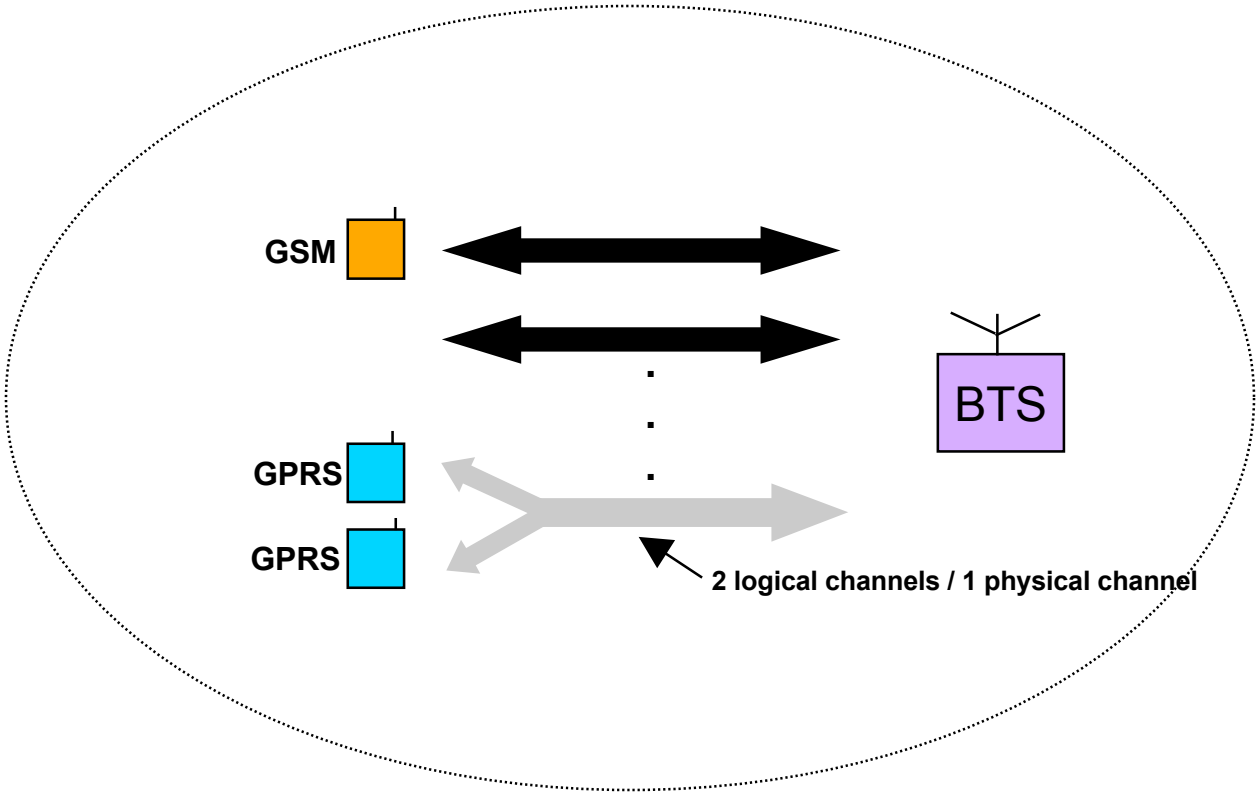
Goals

- 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



cell

Circuit or Packet for Voice traffic

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

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

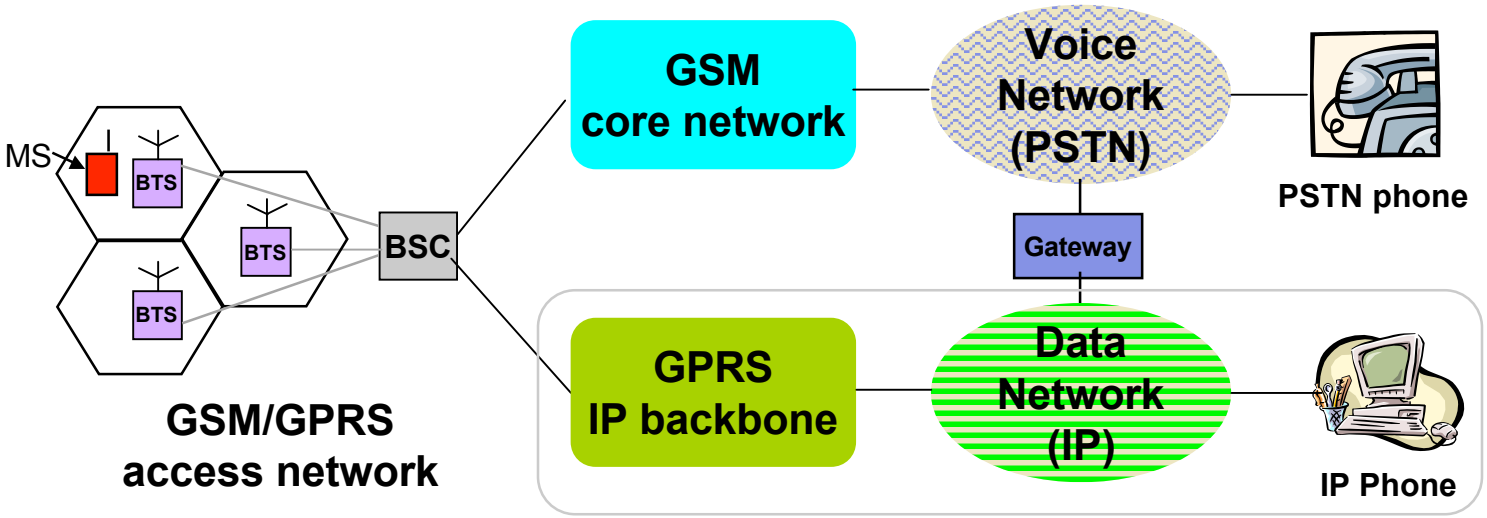
Challenges

- 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

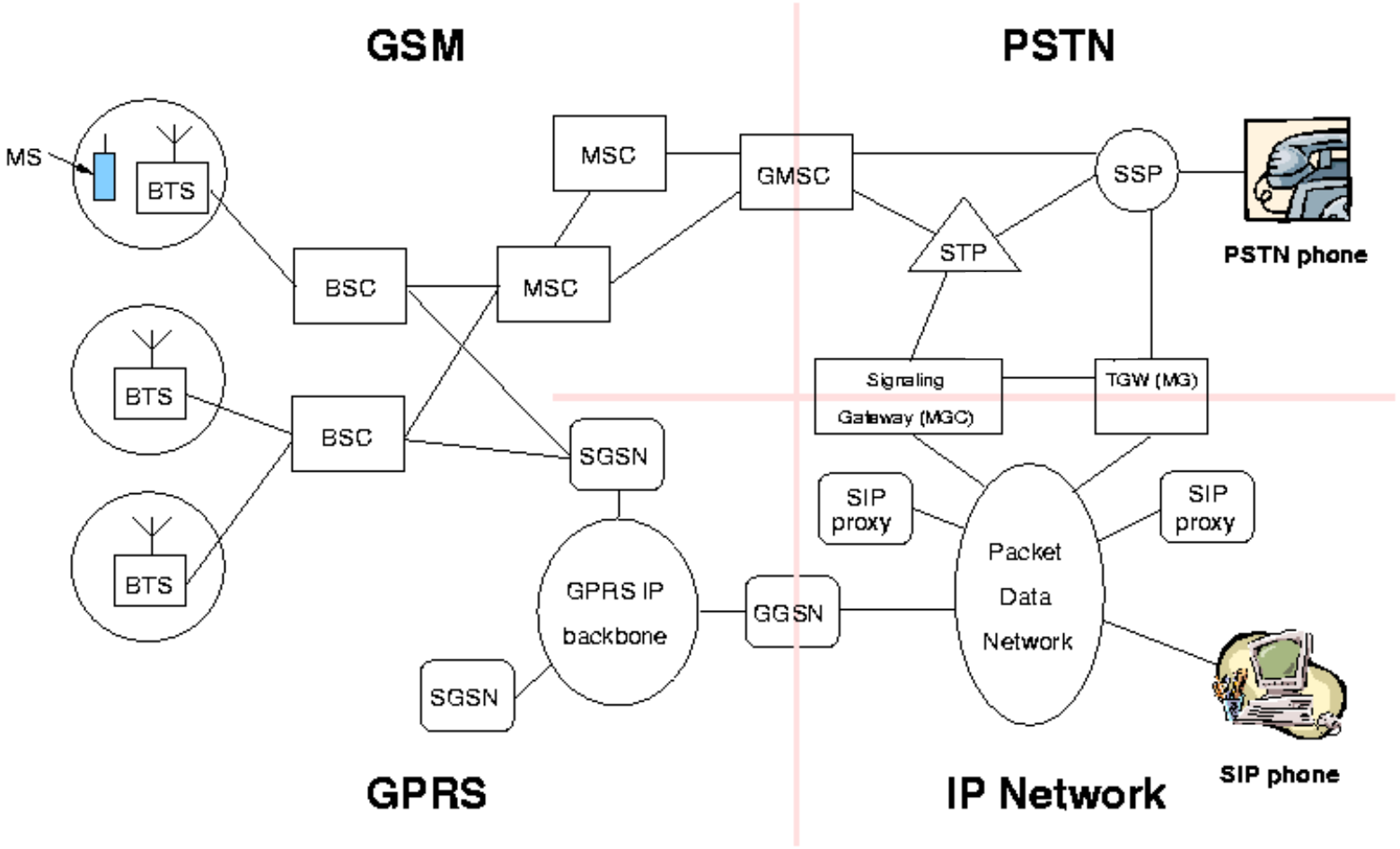
General Packet Radio Service



- 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

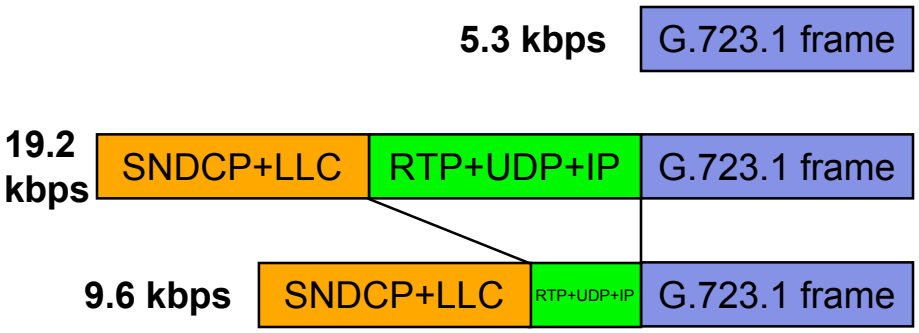
Internetworking among GPRS, GSM, PSTN, and IP network

- **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



- *G.723.1* codec (5.3 kbps version) generates 20-octet frames every 30ms
- SNDCP(5)/LLC(7)/RTP(12)/UDP(8)/IP(20) headers are added
- 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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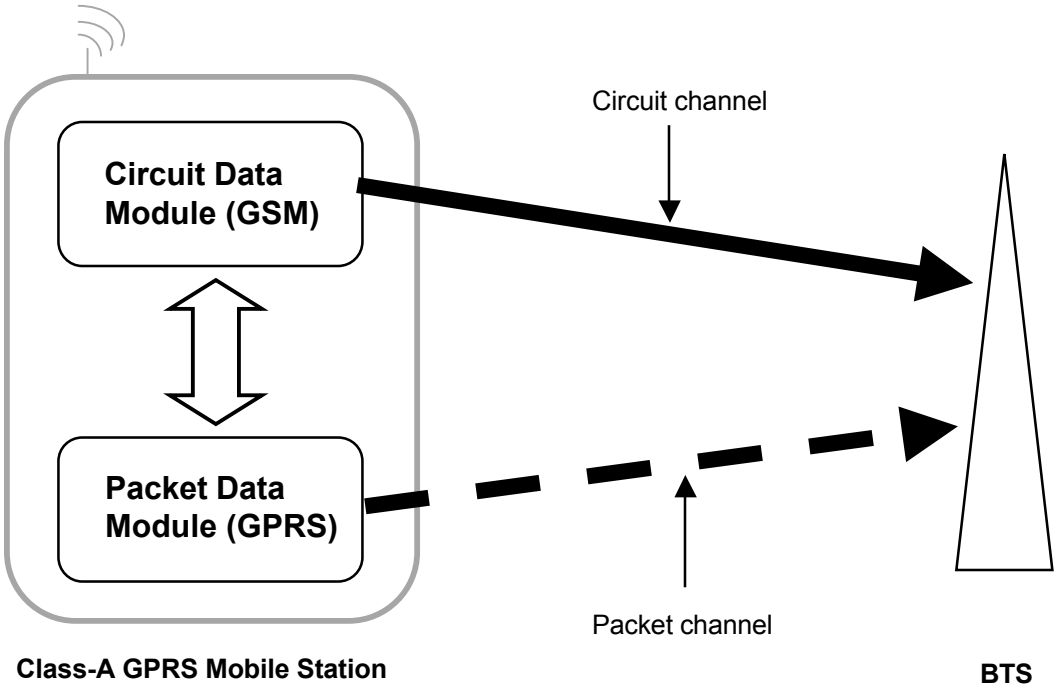
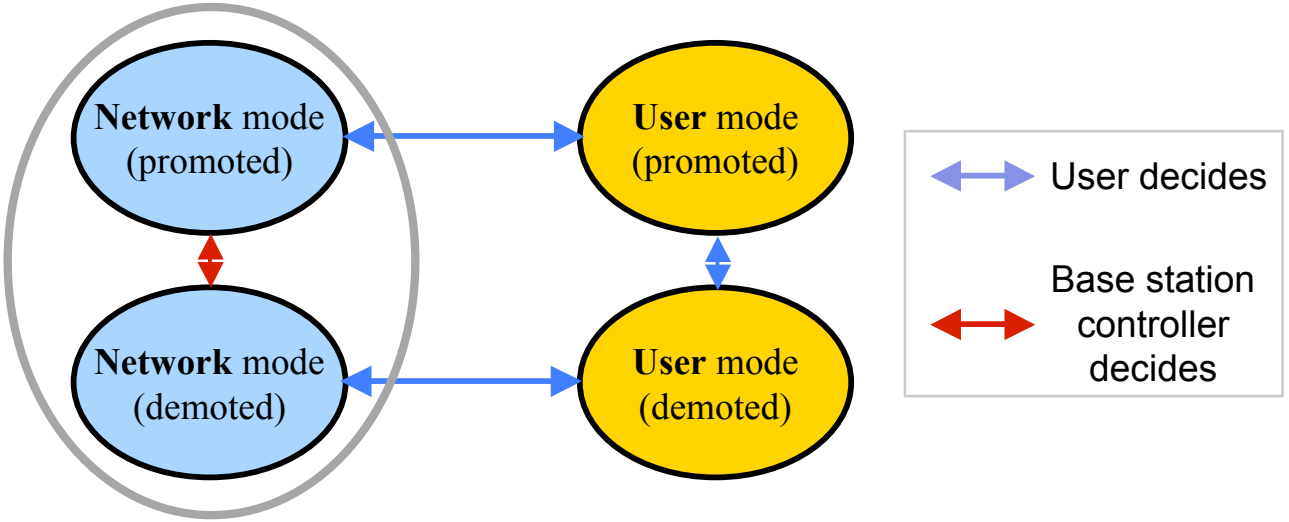
Promotion & Demotion



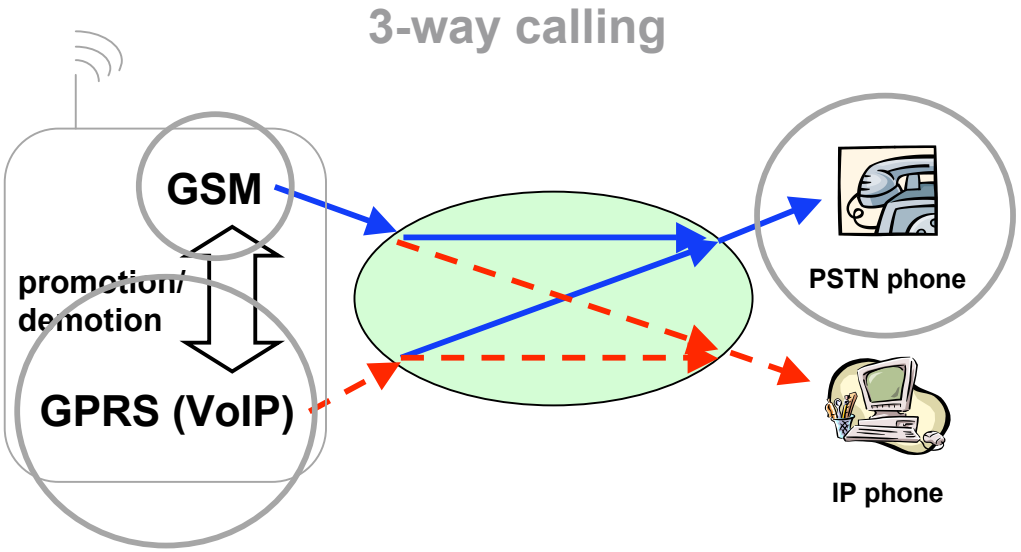
- Promotion: VoIP (packet) -> GSM (circuit)
- Demotion: GSM (circuit) -> VoIP (packet)

Mobile Station States



- Network mode
  - pro/demotion are driven 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 give higher priorities

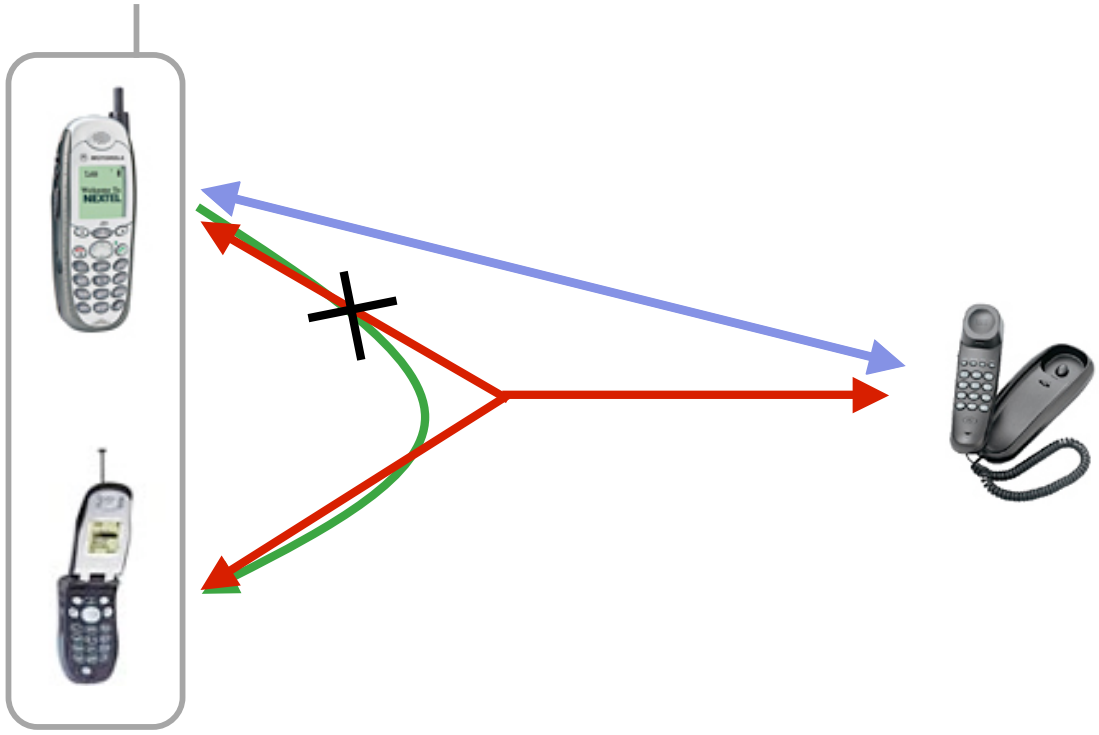
Pro/demotion by 3-way calling



Class-A GPRS Mobile Station

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

3-way calling

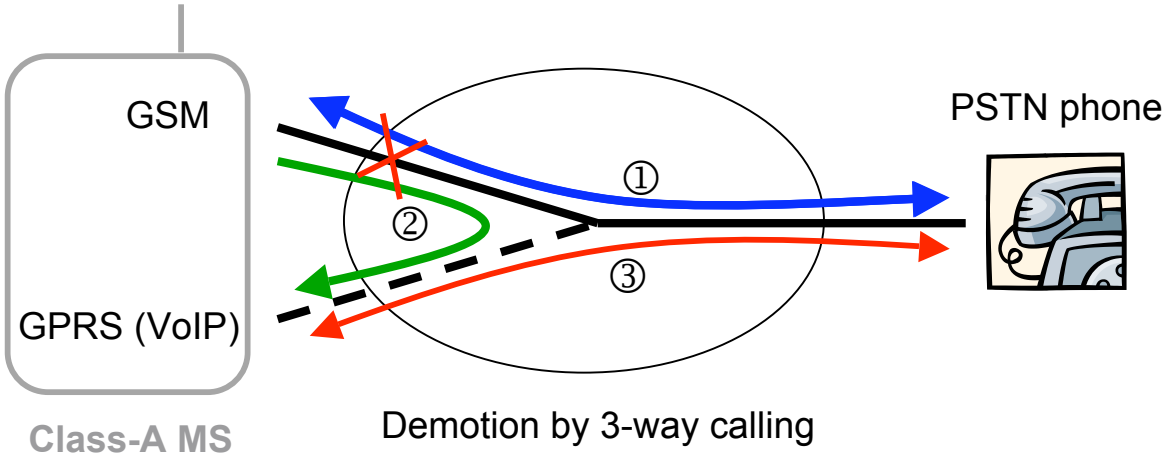


Class-A GPRS phone

3 Bandwidth Adaptive Toggle Schemes

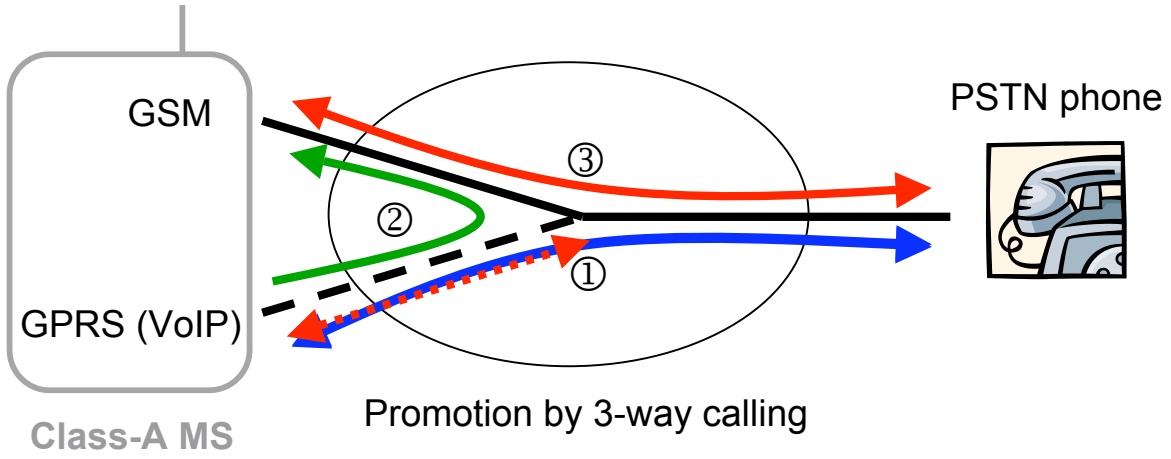
- Circuit-based scheme
- Packet-based scheme
- Hybrid scheme

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

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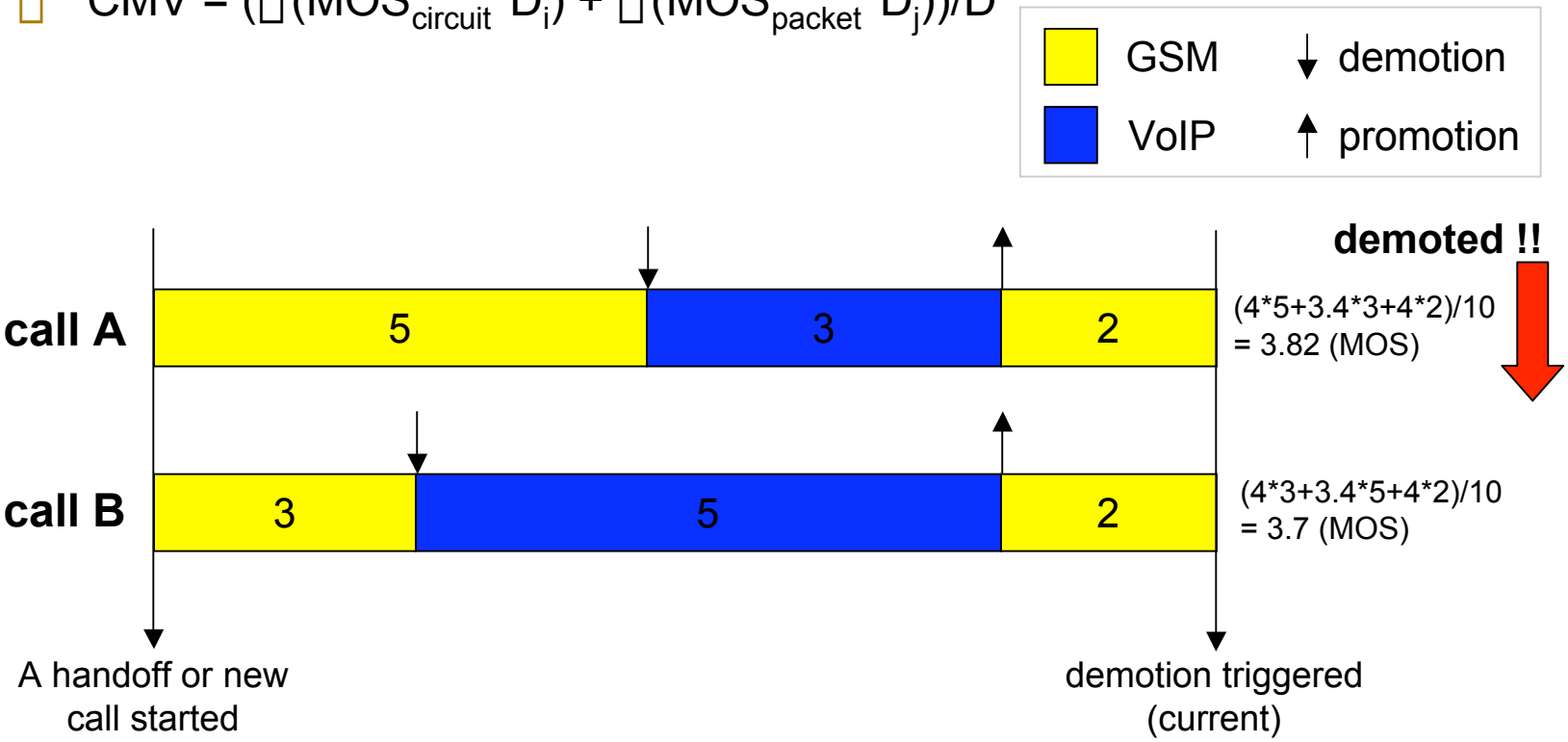
3 Criteria

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

Cumulative MOS

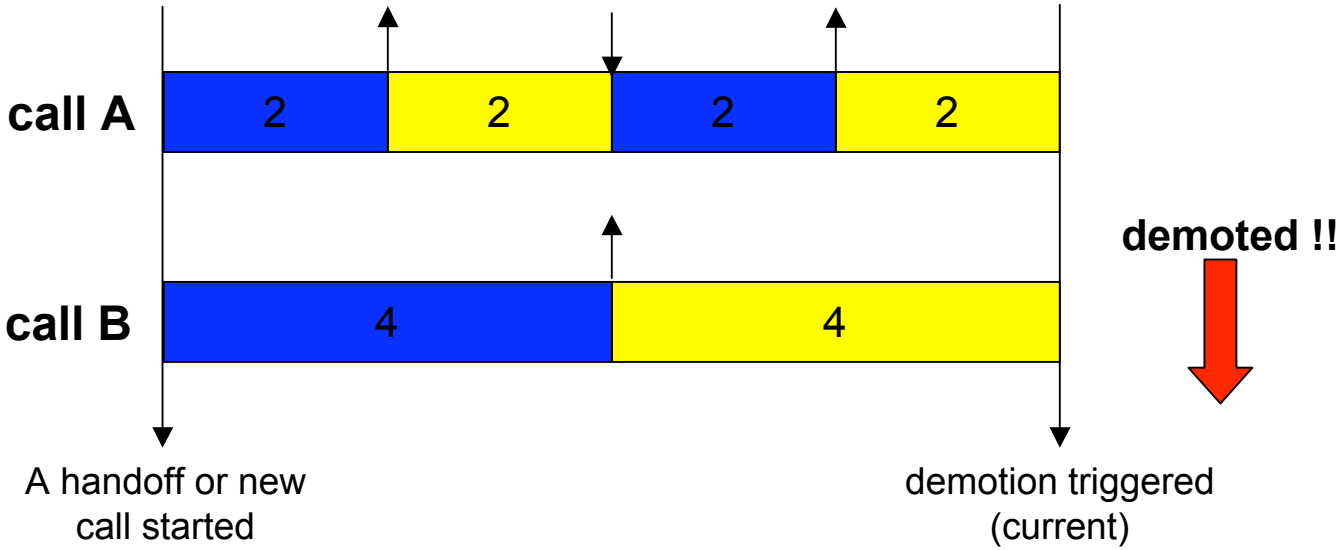
- Standardized ranking system for measuring call quality
- Mean Opinion Score
  - 5-point (from excellent(5) to bad(1))
  - GSM (Enhanced Full Rate) : 4.0
  - VoIP (G.723.1 with 3% frame loss rate) : 3.4

CMV = ($\sum$(MOS$_{circuit}$*D$_i$) + $\sum$(MOS$_{packet}$*D$_j$))/D



Hiccups

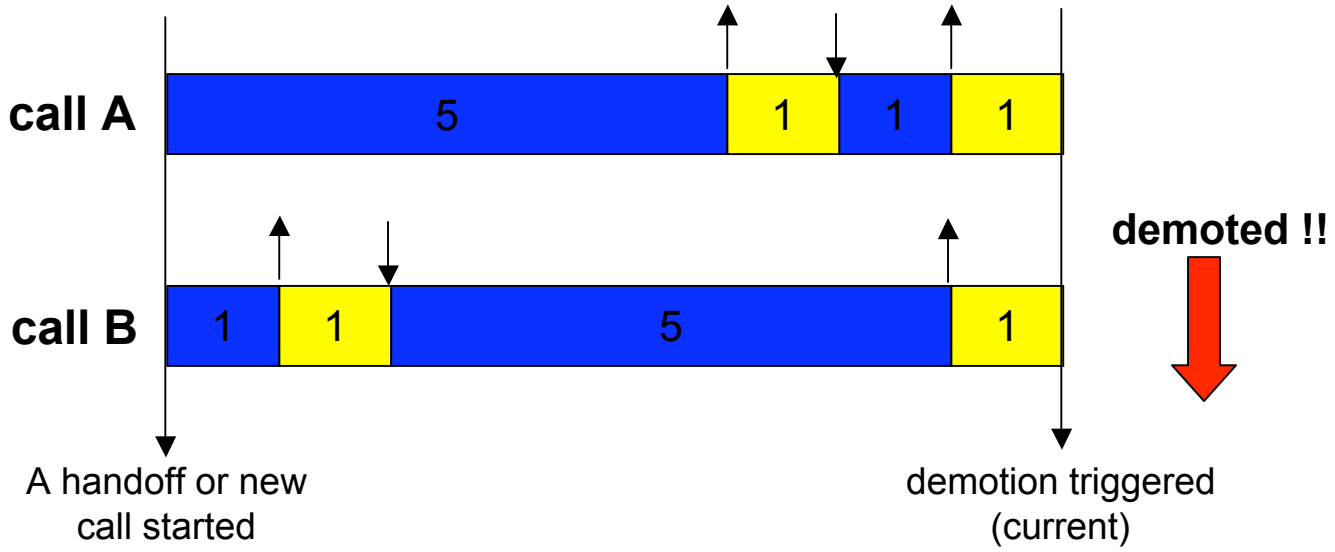
- When demotion or promotion is performed, users may experience hiccups or delays
- The number of hiccups should be minimized and at the same time they should be distributed evenly throughout the call



GSM

VoIP

Hiccups (con't)

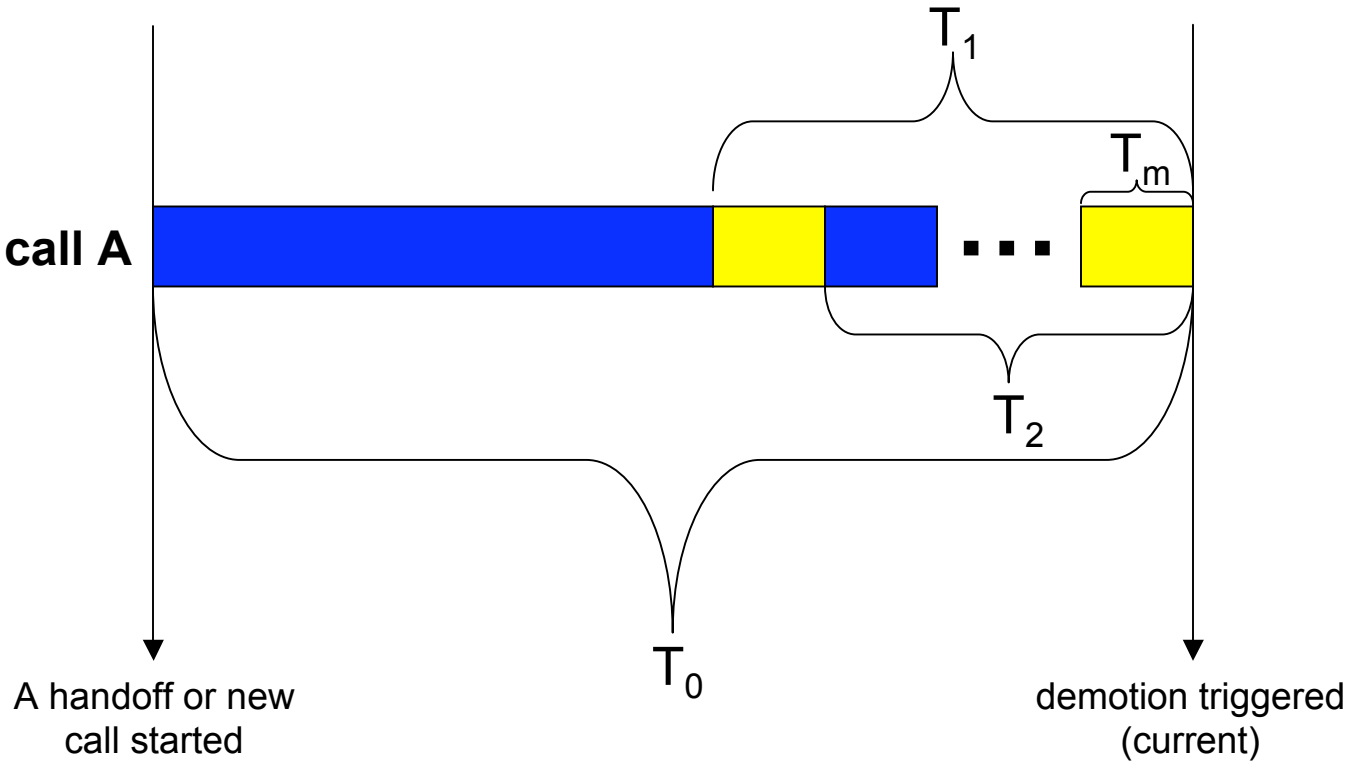


GSM

VoIP

Hiccups (con't)

- CHV = 1 / (A_0/T_0 + □(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 □ A_d : circuit-based scheme
    - A_p >> A_d : packet-based and hybrid scheme



Call duration in a cell

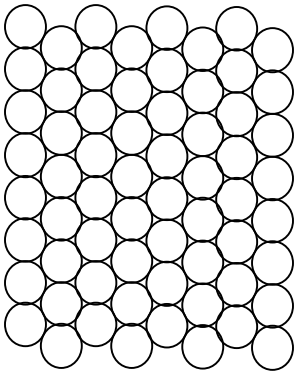
- Why call duration ?
  - It is not desirable to demote or promote the calls that have been initiated or handoff-ed recently
  - It is not desirable to demote or promote the calls which will handoff soon (calls of fast moving users)
  - Above two kinds of calls have small call duration in the current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

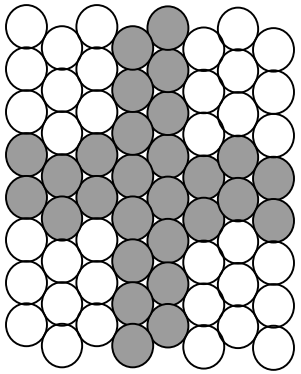
- Two Utility Functions
  - Combined Utility
    - $Utility_i = a*CMV_i + b*CHV_i + c*CDV_i$
    - a, b, and c are weight values and configured by the base station controller
  - Prioritized Utility
    - $Utility_i = Priority(Permute(CMV_i, CHV_i, CDV_i))$
    - Each cell can have a different *Permute*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



Plain

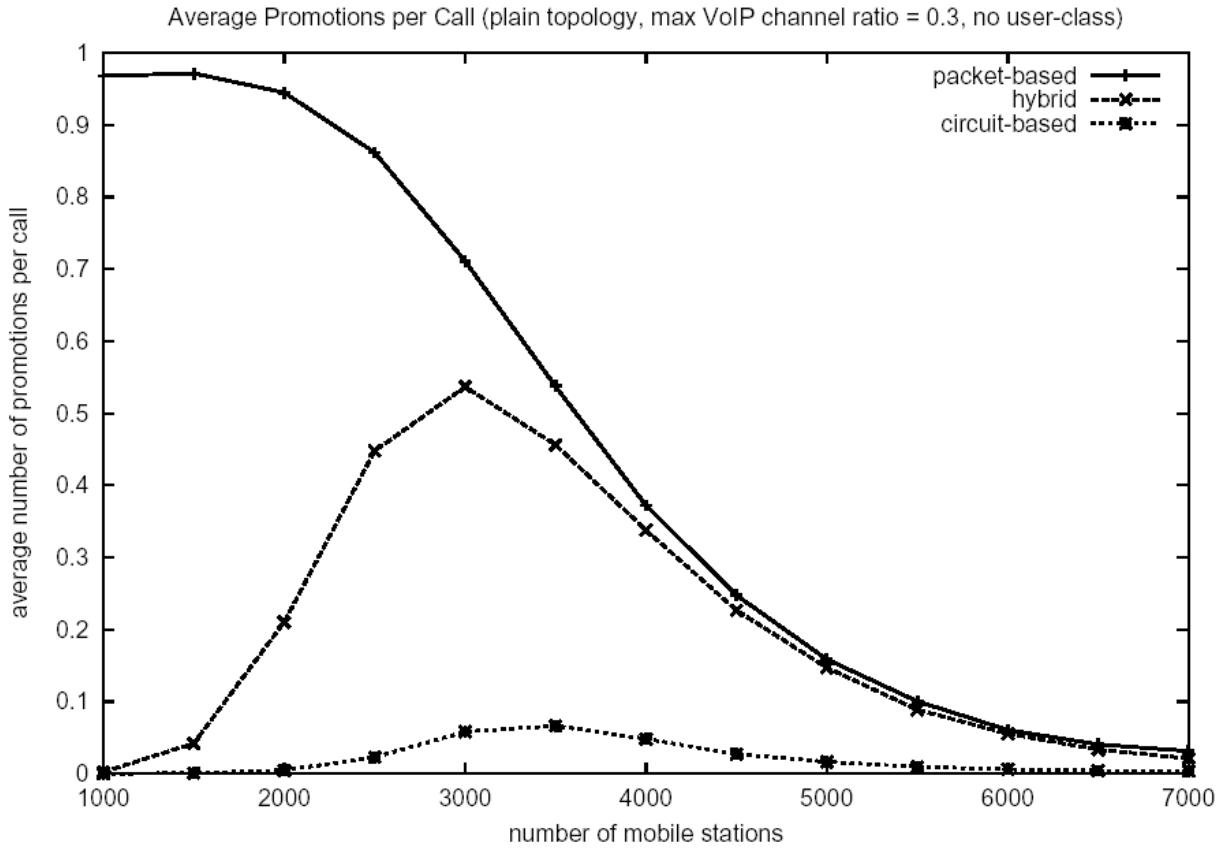


Intersection

Simulation parameters

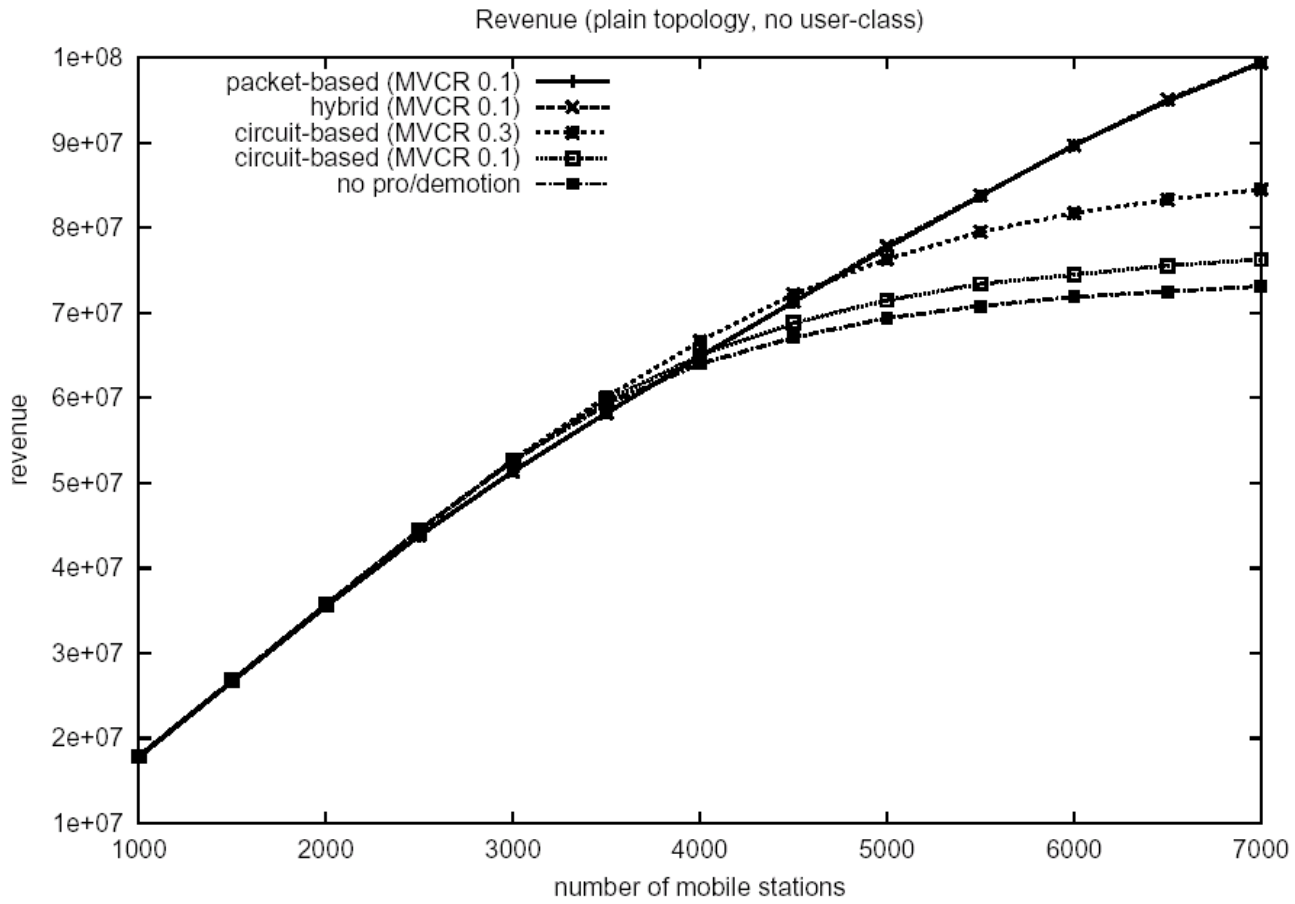
Network Size	**8 X 8 cells**
Network Topology	**plain, intersection**
Traffic Channels per Cell	**50**
VoIP calls per physical channel	**2**
Number of Mobile Stations	**1000..7000**
Mobile Station Movement	**directed**
Average Call Length (exponential)	**180 sec**
Average Idle Time (exponential)	**100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

Number of Promotions per Call



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

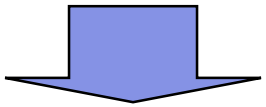
Revenue



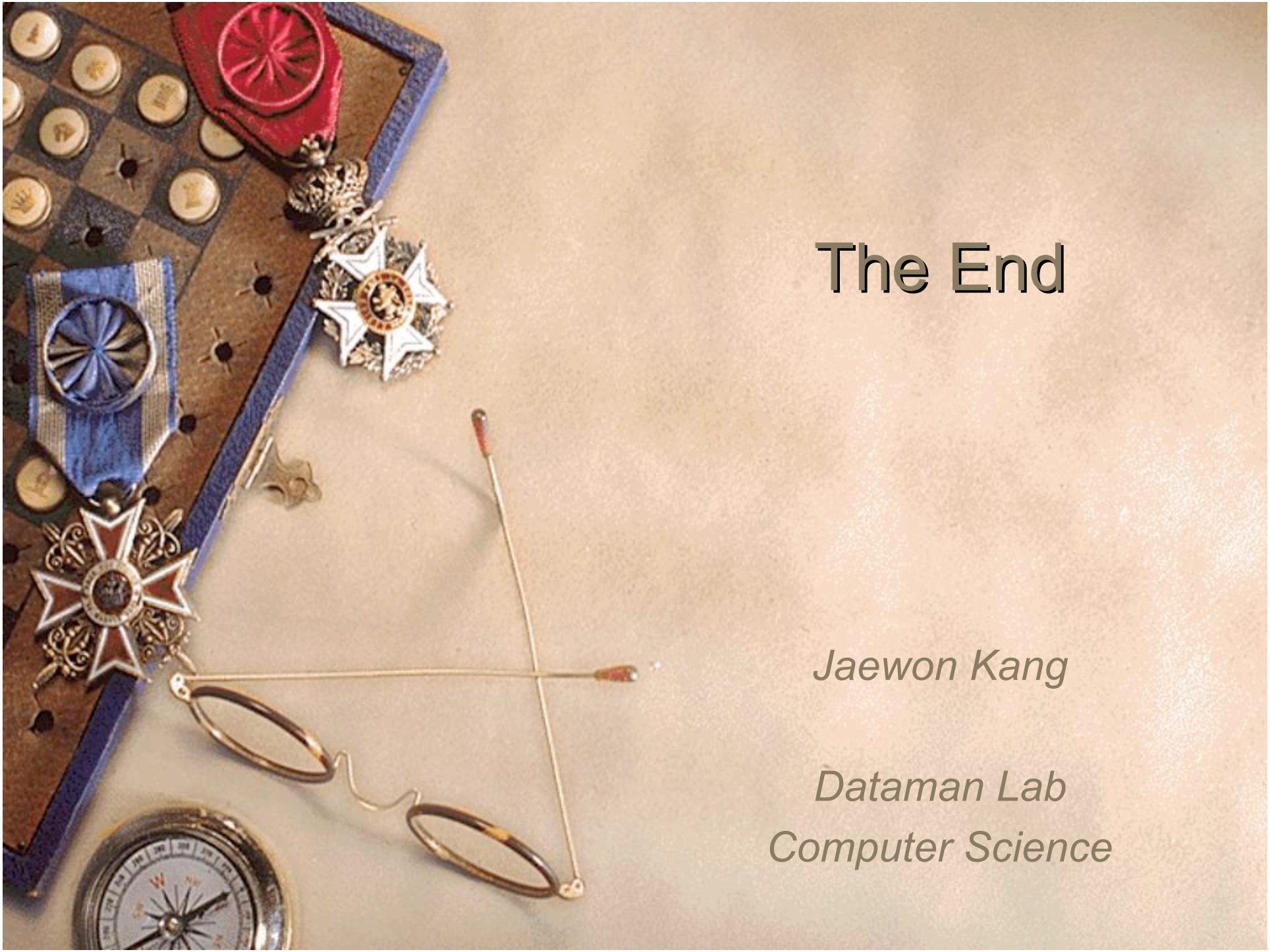
- Only cumulative MOS is considered for revenue
- Hybrid scheme triggers VoIP for new calls too early

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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