CROSS-LAYER DESIGN FOR QoS WIRELESS COMMUNICATIONS

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The purpose of the authors

- To propose a Joint cross-layer design between MAC layer and Physical layer for QoS content delivery

- With providing QoS-awareness scheduler and power adaptation scheme at both uplink and downlink MAC layer

- In order to coordinate the behavior of Physical layer to use the resources efficiently

Why cross-layer design?
What is wrong with the classic layer approach?

- Mobile cellular networks, evolving to carry both voice and data services: “the future of wireless internet centric systems”

- In meeting QoS requirements for wireless systems, there are some problems to design these all IP wireless systems.
  Mainly:

  - Dynamic Link Characteristics
  - Resource Contention

Why cross-layer design? What is wrong with the classic layer approach? (Contd.)

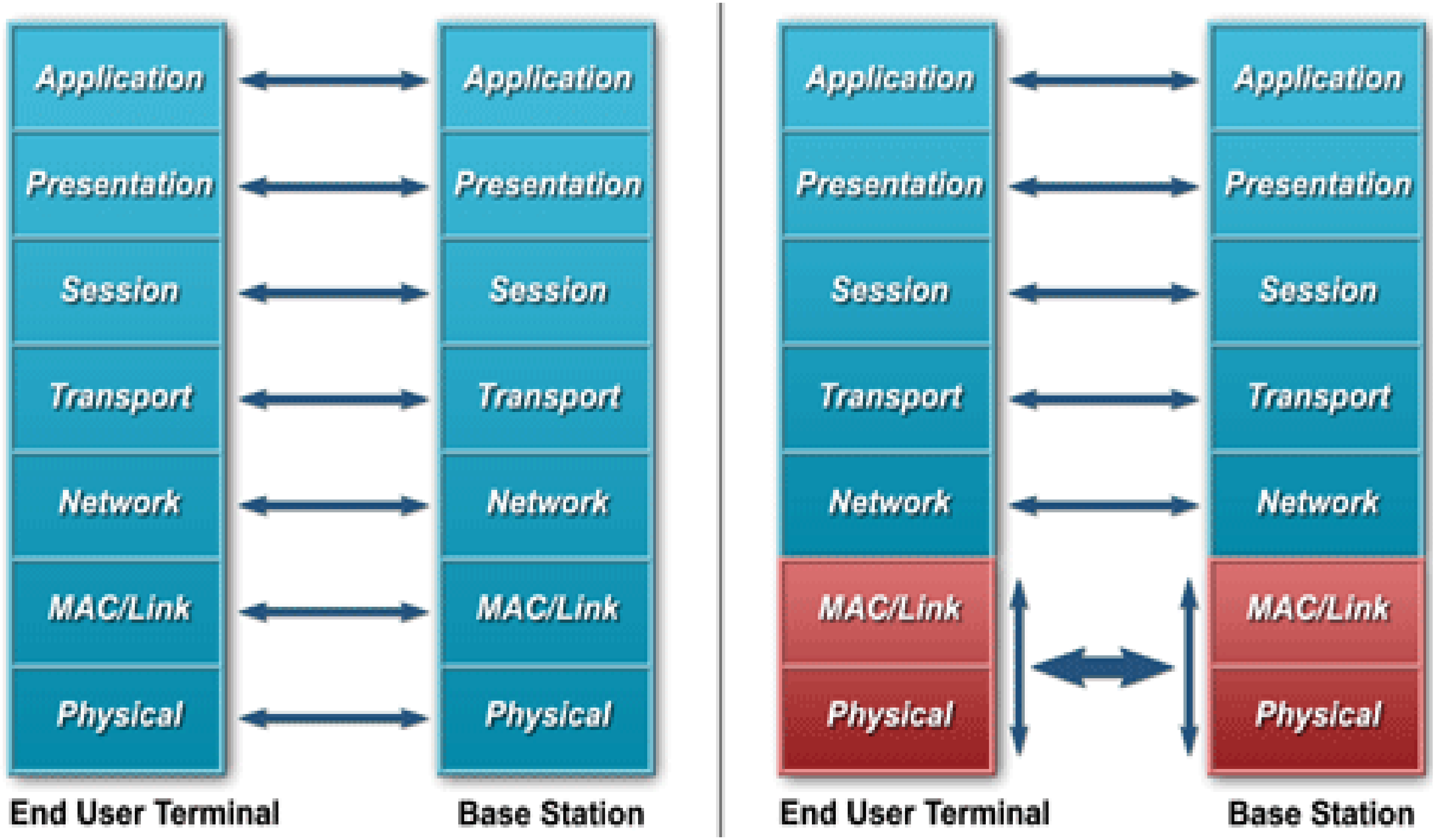
- The solution to these difficulties requires dynamic behavior
- The conventional layer approach is not dynamic, it is inflexible, various protocol layers can only communicate in a strict manner
- In the traditional approach, the layers are designed to operate under the "worst" conditions! They are not designed to adapt to changing conditions
- This causes inefficient use of spectrum and energy

Why cross-layer design?

- Cross-Layer design is based on adaptation
- Adaptation: the ability of network protocols and applications to observe and respond to the channel variation

What is authors' cross-layer design approach?

- Proposed QoS-awareness MAC scheduler selects appropriate transmission format and priorities of the packets for each user depending on its present channel condition

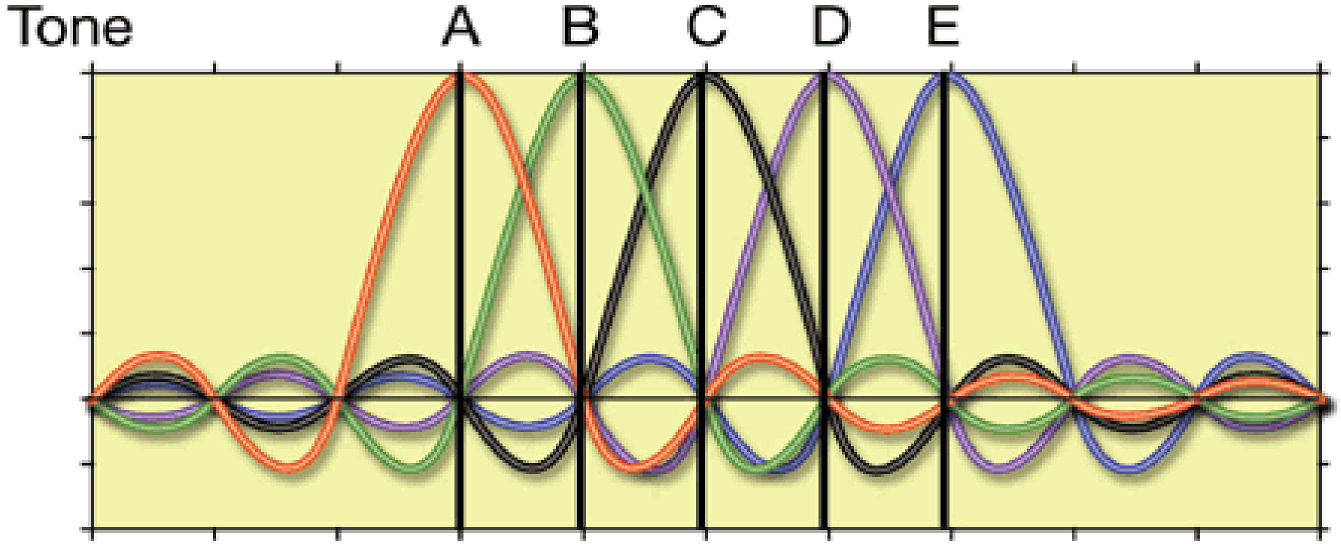


System Architecture

- Based on RNS-OFDM :
  (Residue Number System–Orthogonal Frequency Division Multiplexing)

- OFDM's main feature:

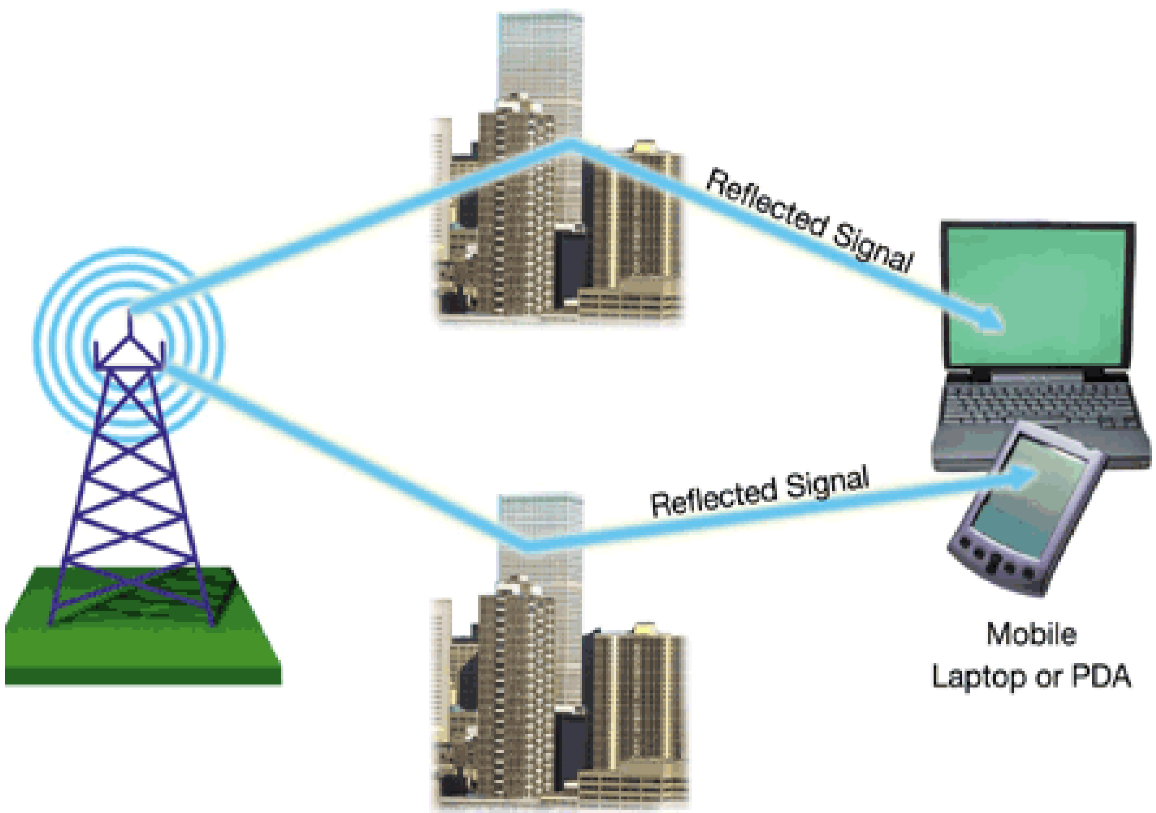
  - OFDM–based data systems typically divide the available spectrum into a number of equally spaced tones. For each OFDM symbol duration, information carrying symbols (based on modulation such as QPSK, QAM, etc.) are loaded on each tone.



System Architecture (Contd.)

- Absence of "intracell interference" because of the orthogonality of subcarriers.

- The orthogonality is preserved even in the presence of multipaths.



System Architecture (Contd.)

- The intercell interference is averaged across cells because the user sub-carriers employ fast hopping.

- Fast-hopped OFDM (also known as Flash OFDM) : considered the most advanced cellular system in the world for "packet-switched", mobile broadband IP services.

- Fast-hopped OFDM (Flash OFDM), was concieved at Bell Laboratories by the founders of Flarion Technologies (www.flarion.com) in 1997

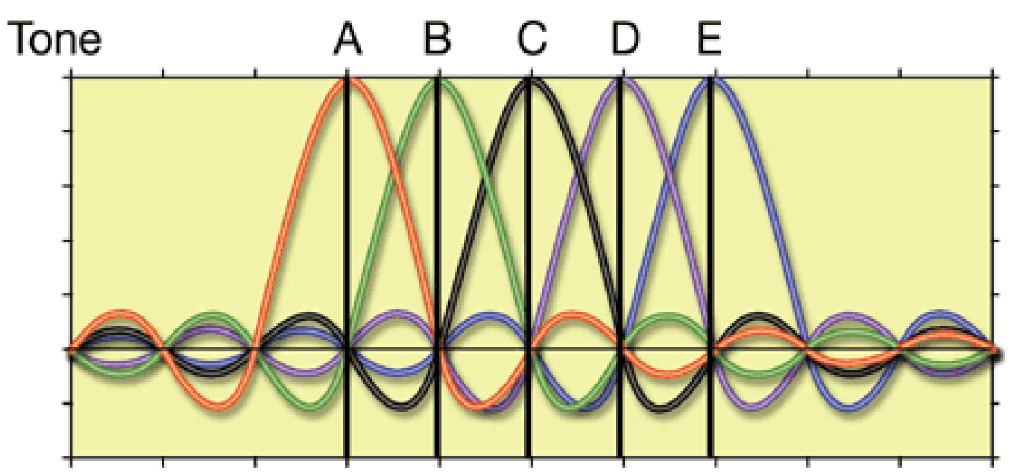
- It was developed as an all-IP answer to the concerns of data transmission over GSM and CDMA "circuit-switched" networks.

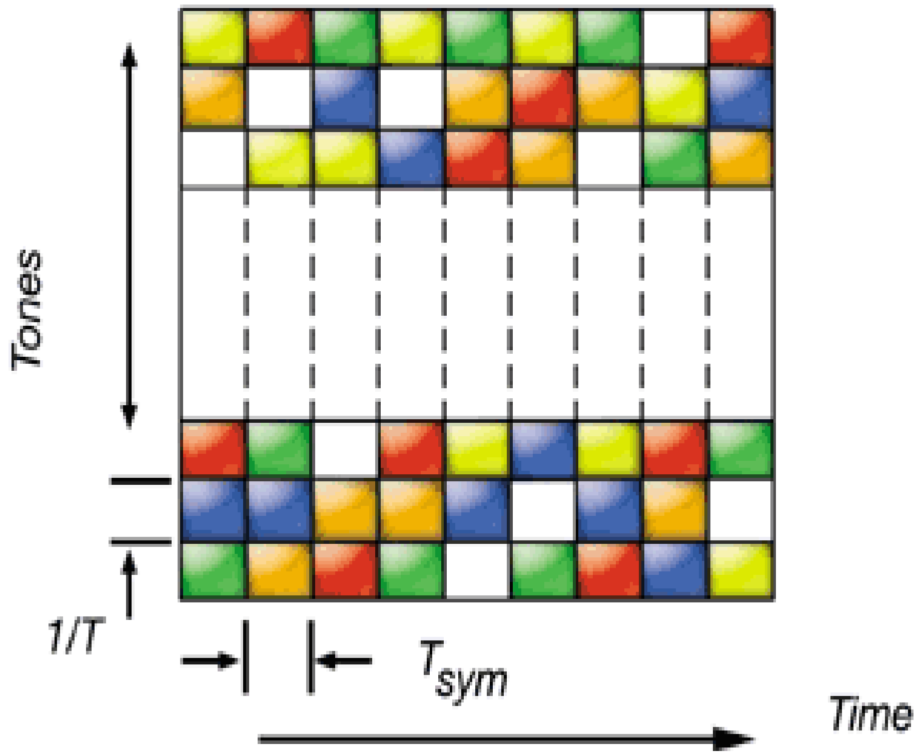
System Architecture (Contd.)

- Downlink: "Shared pilots" are used for the physical layer

  - Pilot: a reserved sub-carrier that is sent by the base station

- This eliminates pilot overhead for data and control frames





System Architecture (Contd.)

- Each user is assigned a user-signature frequency-hopping pattern also referred to as an "address RNS code"

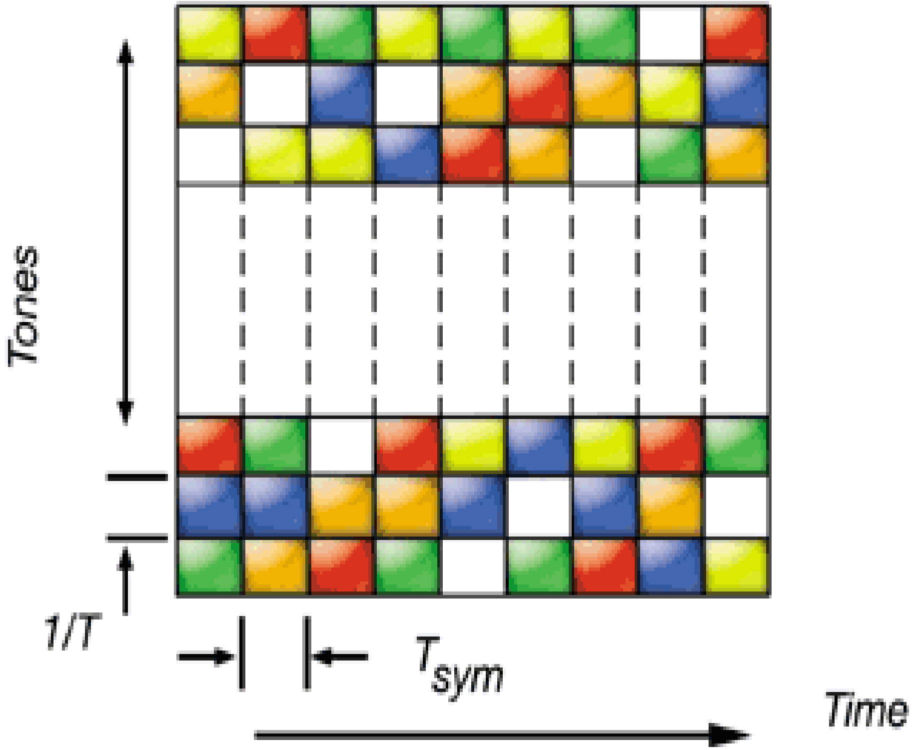
- During the transmission, users have a dedicated control channel with both control and traffic channel power and timing controlled without disturbing QoS requirements

- Uplink: Signals are transmitted as a sequence of symbols that are formed in the same way as the downlink symbols are, in both time and frequency domains

- Uplink physical layer does not use pilot symbols

System Architecture (Contd.)

- Uplink physical layer does not use pilot symbols: it is hard to establish phase reference for coherent modulation.
- Dormant time: if the mobile stays in one tone for several symbol periods, this is called as "dormant time". This helps the receiver establish phase reference.



System Architecture (Contd.)

- The uplink signal is *power-controlled* and *timing-controlled*.

- The mobile terminals periodically transmit the wideband multisubcarrier signals to allow the closed-loop timing control.

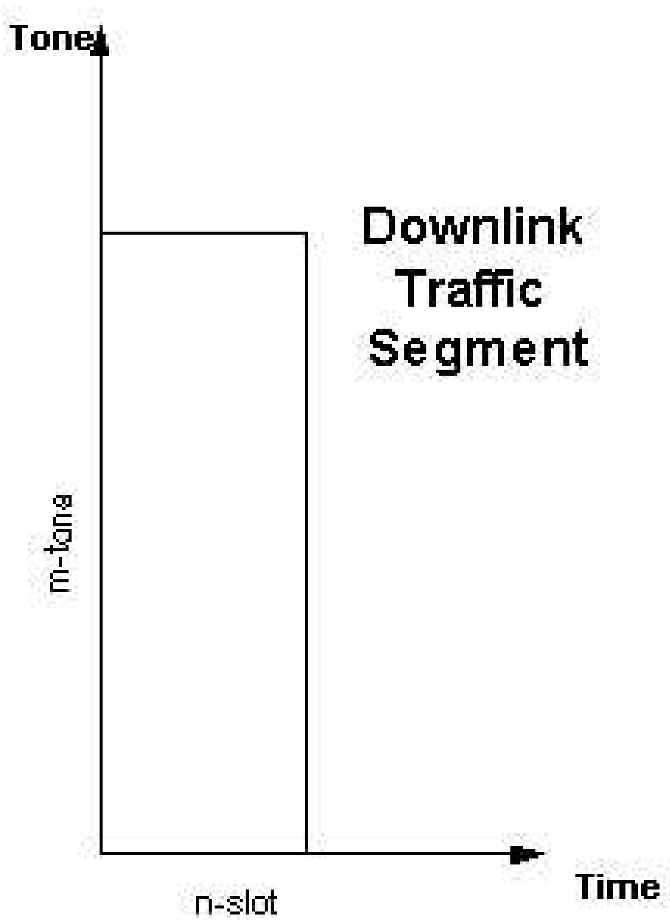
  - Systems that utilize feedback are called *closed-loop* control systems.

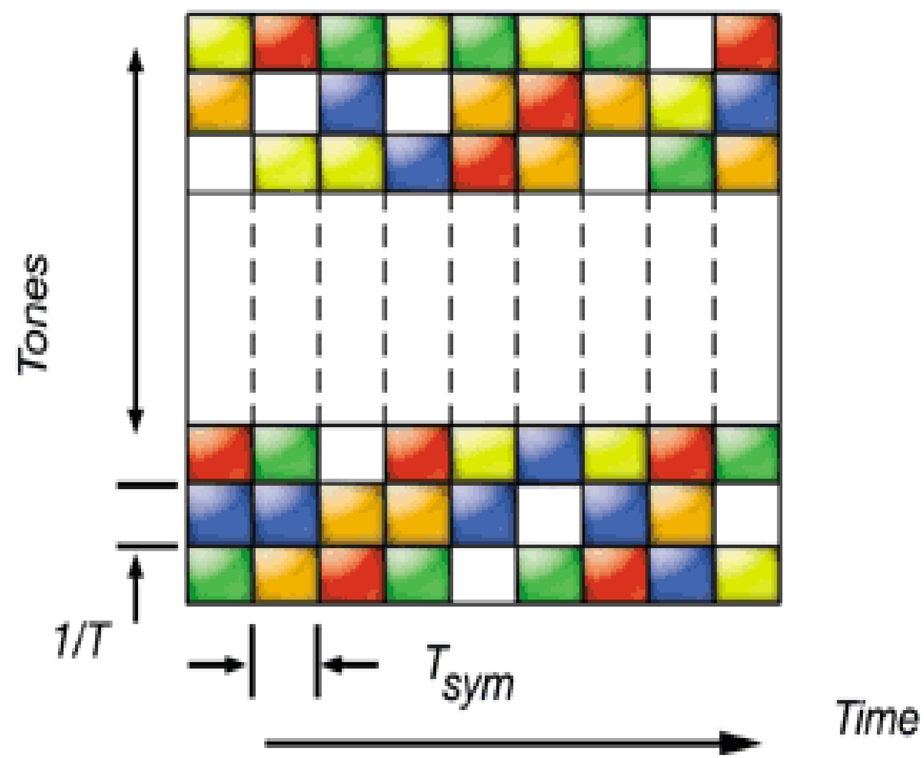
  An *open-loop* control system doesn't have or doesn't use feedback.

System Architecture (Contd.)

- In the proposed MAC design, a *segment* is the minimum transmission unit of data on the traffic channels.

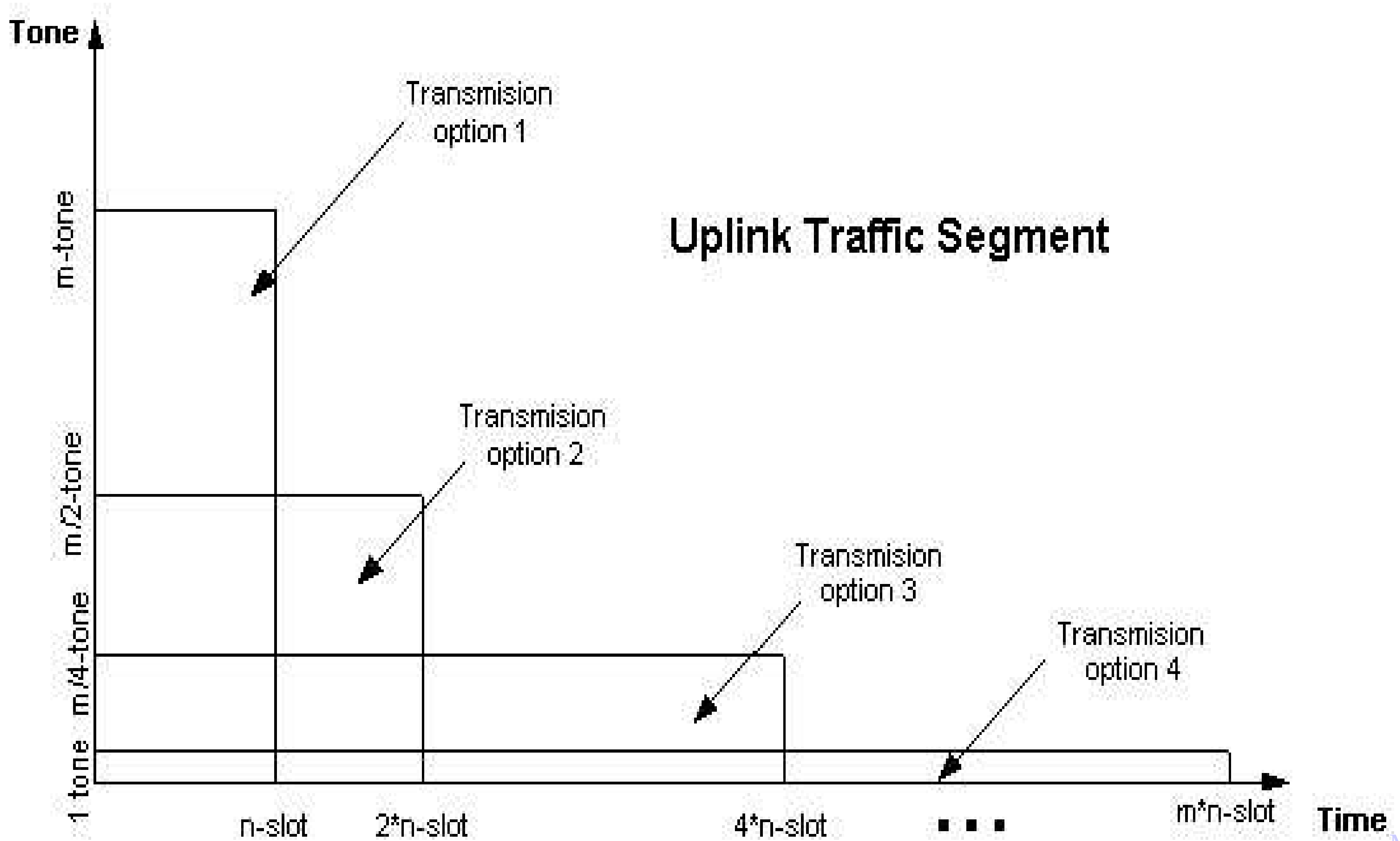
- As an instance, a downlink traffic channel segment consists of *“m tone sub-carriers”* by *“n time slots”* as shown in the figure below.





System Architecture (Contd.)

- The uplink transmission supports different transmission options (power adaptive) as shown in the figure below



MAC assign.
MAC assign. II

System Architecture (Contd.)

- Within each time slot, there are two traffic channel segments: "data" and "control" channel segments.

- Out of the total sub-carriers available in each symbol period, certain number of sub-carriers are reserved for signaling such as:

  - The acknowledgments of uplink data, and

  - The assignments of both uplink and downlink segments.

Proposed Cross-Layer QoS Design

- QoS-aware and Power-adaptive MAC States
- Assignment of MAC States
- QoS-aware and Power-adaptive Transmission

QoS-aware and Power-adaptive MAC States

- 3 Different QoS-aware MAC states for both uplink and downlink transmissions:

  I- High-QoS
  II- Media-QoS
  III- Low-QoS

- The base station dynamically schedules users in “different” MAC states based on:

  - Resource availability
  - Overall QoS

QoS-aware and Power-adaptive MAC States (Cont.)

- Overall QoS:

$$QoS = QoS_{class} * QoS_{stream}$$

- QoS_{class} : Determined by service priority/pricing (for example: How much a user pays for a monthly service)

- QoS_{stream}(traffic class): Determined by the characteristics of data traffic.

QoS-aware and Power-adaptive MAC States (Cont.)

I- High-QoS State

- Users are actively sending and receiving traffic.
- The channels for user traffic are shared among these high-QoS users.
- Traffic segments are instantaneously assigned to any high-QoS user when there is data to send or receive.

QoS-aware and Power-adaptive MAC States (Cont.)

II- Media-QoS State

- Users have *contention-free* uplink request slots to indicate to an IP-base station that they have data to send.

- Users also have shared downlink message slots

- These shared downlink message slots are timing-controlled, but not power-controlled.

QoS-aware and Power-adaptive MAC States (Cont.)

III- Low-QoS State

- This state is proposed especially for power saving
- Users only maintain connectivity to an IP-base station and stay in sleep mode.
- They stay in sleep mode until there is an incoming session.
- Theyhave shared downlink *paging* slots:

  They wake up periodically and listen for incoming pages from the IP-base station.

QoS-aware and Power-adaptive MAC States (Cont.)

Transition among MAC states

- The base station uses the *QoS "identification number"* to distinguish different QoS users.

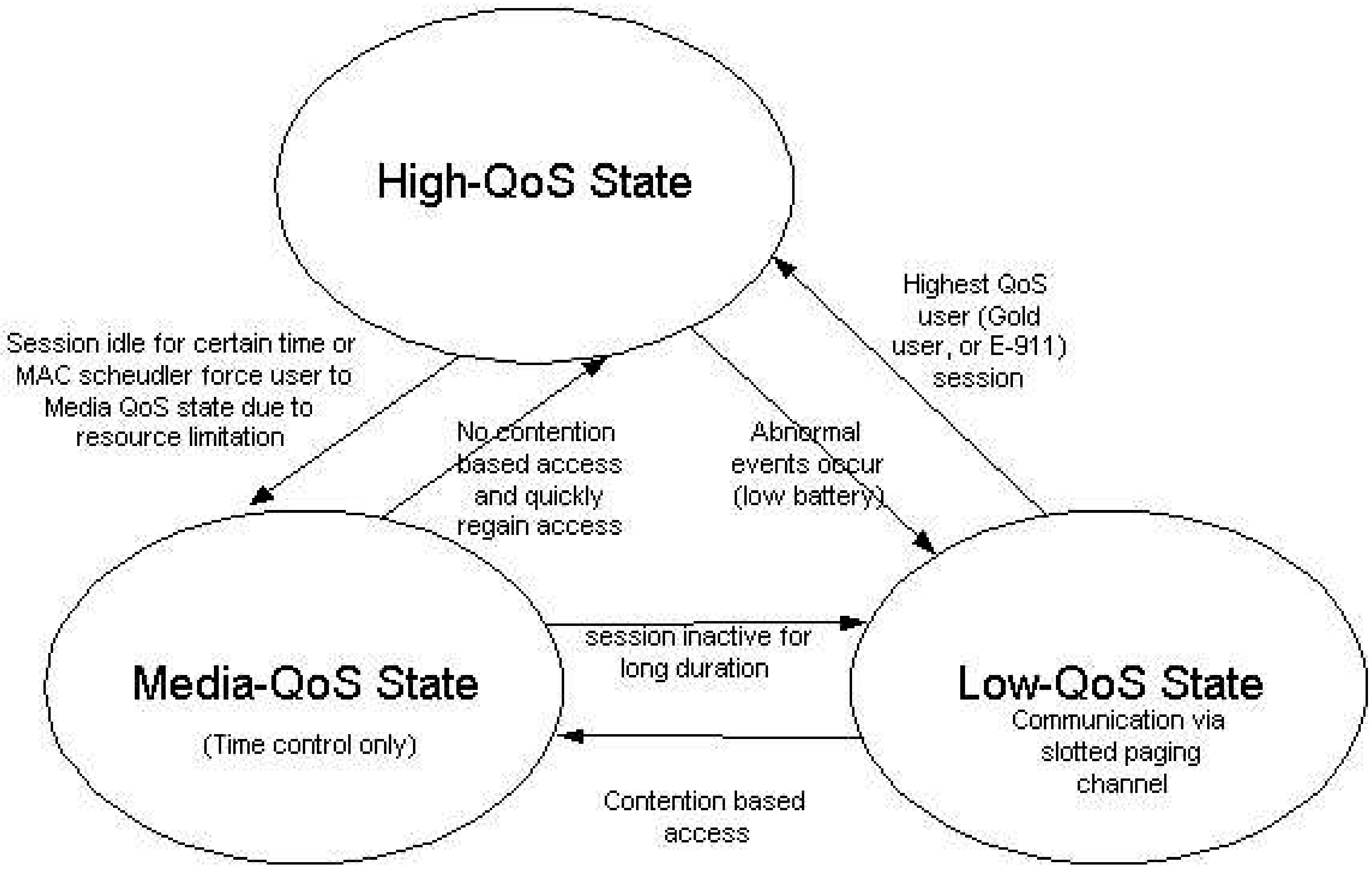
- High-QoS identifier is dynamically allocated to a mobile when it migrates to "high-QoS" state and is revoked when it migrates out of "high-QoS" state.

- At mobile node side, there are three different QoS-aware MAC states corresponding to those at the base station (*High-QoS*, *Media-QoS*, and *Low-QoS*).

- During initial registration stage, a mobile node can request its desired QoS MAC state but the final decision is made by the base station.

QoS-aware and Power-adaptive MAC States (Cont.)

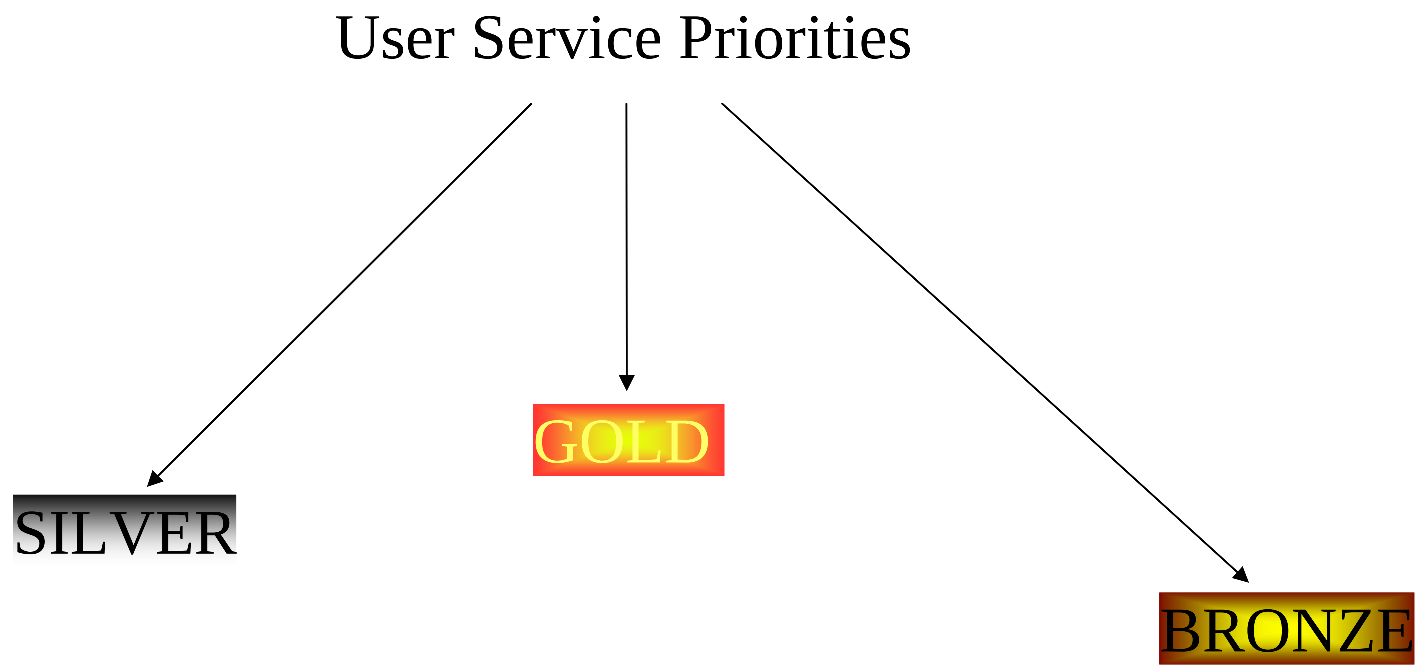
Transition among MAC states



Assignment of MAC States

- In this paper, two factors among many others are considered: *service priority/pricing* and *traffic class*.

- Users are ranked as “Gold”, “Silver”, and “Bronze” service priority:



Assignment of MAC States (Contd.)

- The minimum resolution of traffic is a *"MAC stream"*.
- Examples of MAC streams are shown in the table below:

Stream QoS-ID	Description	BER	SL (Segment Loss)	SO (Segment Order)	Delay
15	E-911 session	4	4	4	4
14	Layer2 control	4	4	4	4
13	Layer3 control	4	4	4	4
12	Circuit voice (G729)	3	3	3	4
11	VoIP (G711-coded)	3	3	3	4
10	Stream video (H263)	3	3	3	4
9	Interactive Data	3	4	4	3
8	Multicast, RTP	3	3	3	3
7	Internet control	4	4	4	4
6	Internet data	3	4	4	2
5	Network manag.	2	2	3	3

Assignment of MAC States (Contd.)

- The combined QoS criteria are used to determine the user's MAC state (High, media, or low?)

$$QoS = QoS_{class} * QoS_{stream}$$

Service priority
(Golden, silver, or bronze?)

Stream QoS-ID
QoS-ID? (5.....15)

QoS-aware and Power-adaptive Transmission

- Channel resources are shared in wireless networks: “resource contention”.

- Conventional schedulers:

  - developed only for downlink transmission(because only the base station has all users' information).

  - uplink transmission typically occurs under the resource contention restriction. It results high delay jitters.

- Most scheduler algorithms work based on maximizing throughput. They do not consider QoS requirements.

QoS-aware and Power-adaptive Transmission (Contd.)

- In the proposed design:

  - The MAC scheduler selects appropriate transmission power/format and priorities of the packets for each user depending on its present channel condition and the associated QoS requirements.

  - Within QoS framework, network level QoS parameters such as BER, segment loss, segment order, and delay have been considered

- Different applications have different QoS network requirements (recall:QoS-ID table):

  - QoS vector [*BER*, *SL*, *SO*,*DEL*] constitutes $Cost_{network}$ of a stream.

QoS-aware and Power-adaptive Transmission (Contd.)

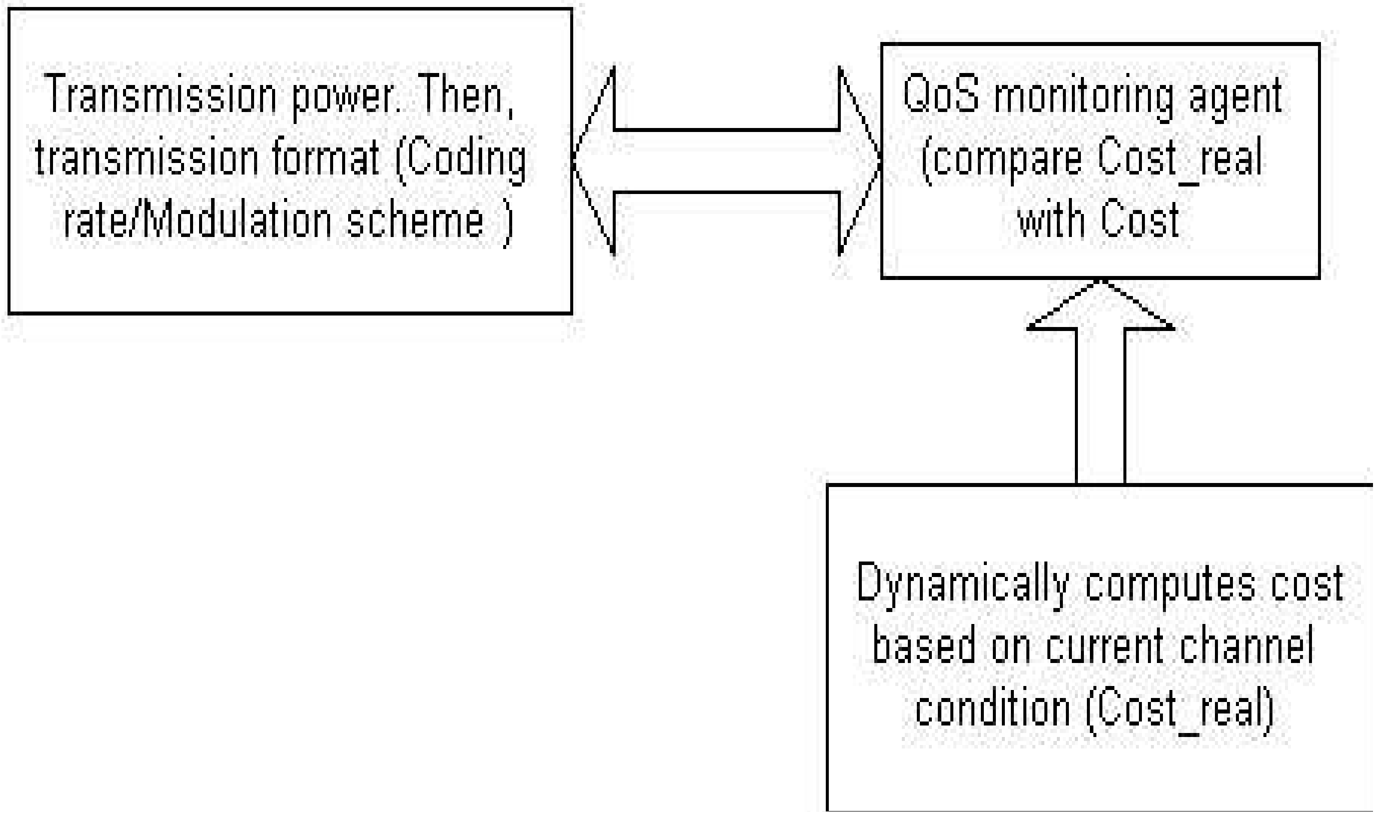
- The network parameters combined with QoS_{class} and QoS_{stream} compose a multicriteria decision for a given user and overall cost measurement is defined as:

$$Cost = QoS_{class} * QoS_{stream} * Cost_{network}.$$

- One can obtain unique cost measurement per frame for a given user based on the characteristic of the different applications.

- The QoS-awareness scheduler determines the power and coding rate required to transmit the given frame with a specific reliability based on multicriteria cost measurement (Cost).

QoS-aware and Power-adaptive Transmission (Contd.)



- MAC scheduler determines physical resource based on cost measurement (applicable for both uplink and downlink traffic).

QoS-aware and Power-adaptive Transmission (Contd.)

- If both power adjustment and transmission format adaptation fail to work, different transmission options can be used in uplink.
- For downlink, only one transmission option is supported as shown in the related figure in previous slides.
- For the uplink, different transmission options are supported as shown in the related figure in previous slides.
- Using different transmission options, the MAC layer allows for multiple classes of uplink transmission power.

QoS-aware and Power-adaptive Transmission (Contd.)

- Bad channel condition + a large number tones
  = exhausting channel resources + degraded performance.

  Instead:

  a smaller number of tones for a longer period of time
  (option 3 or option 4 in the figure).

- The main goal is "to keep the connection alive".

- The expectation is that channel condition gets better during that period.

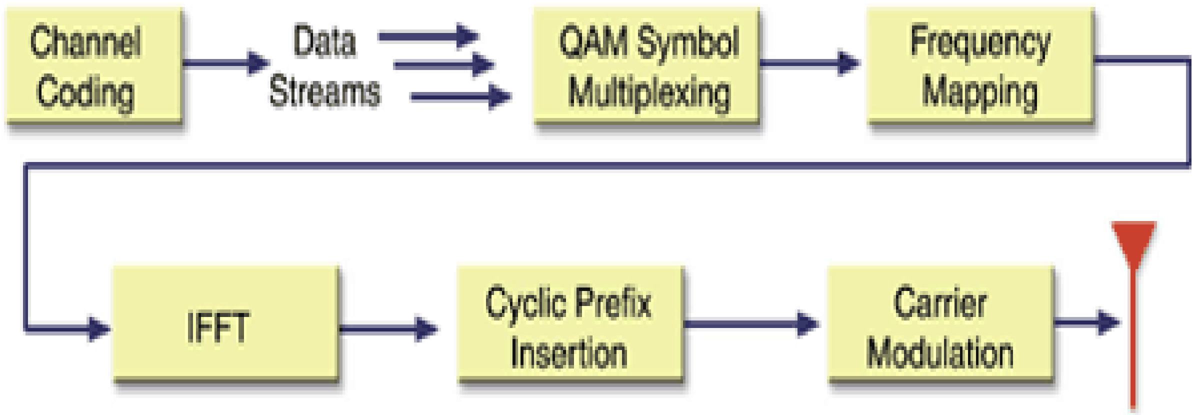
- Good channel condition => a large number of tones for a short period of time (option 1 or option 2 in the figure). Because a good channel condition usually does not last long.

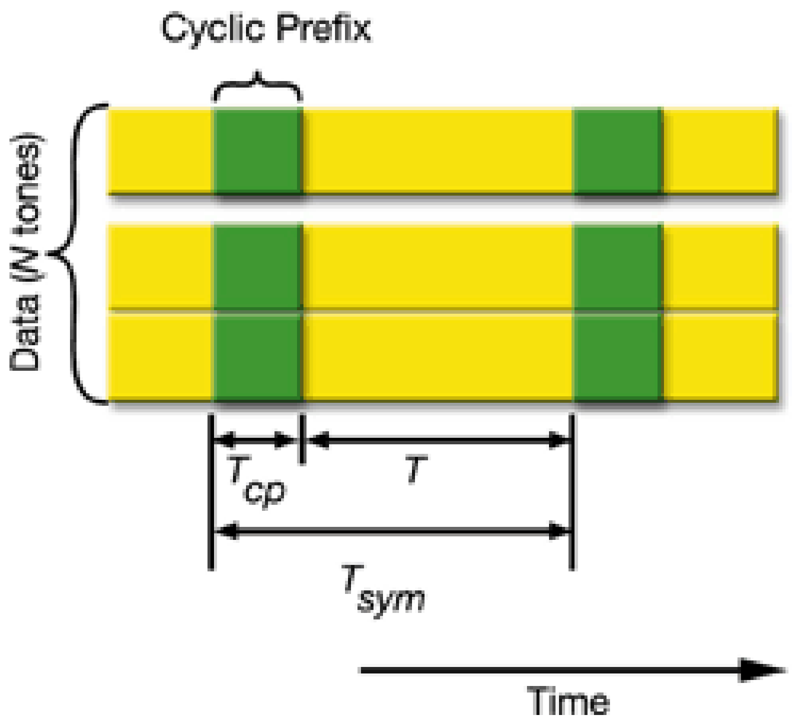
Simulation

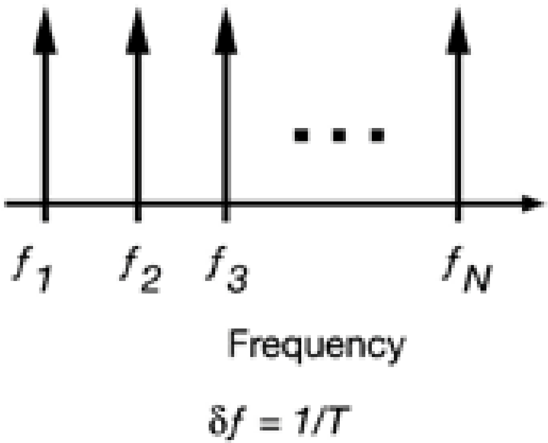
- The basic system parameters are listed in the table below. Testing was conducted in the 700MHz guard band with 1.25MHz channel.

Carrier frequency	up to 5 GHz
Bandwidth	1.25 MHz uplink,1.25 MHz downlink
Number of subcarrier	113
FFT window length	128 samples
Cyclic prefix	16 samples
Downlink peak rate	2.7 Mbps
Uplink peak rate	817 Kbps

Simulation(Contd.)

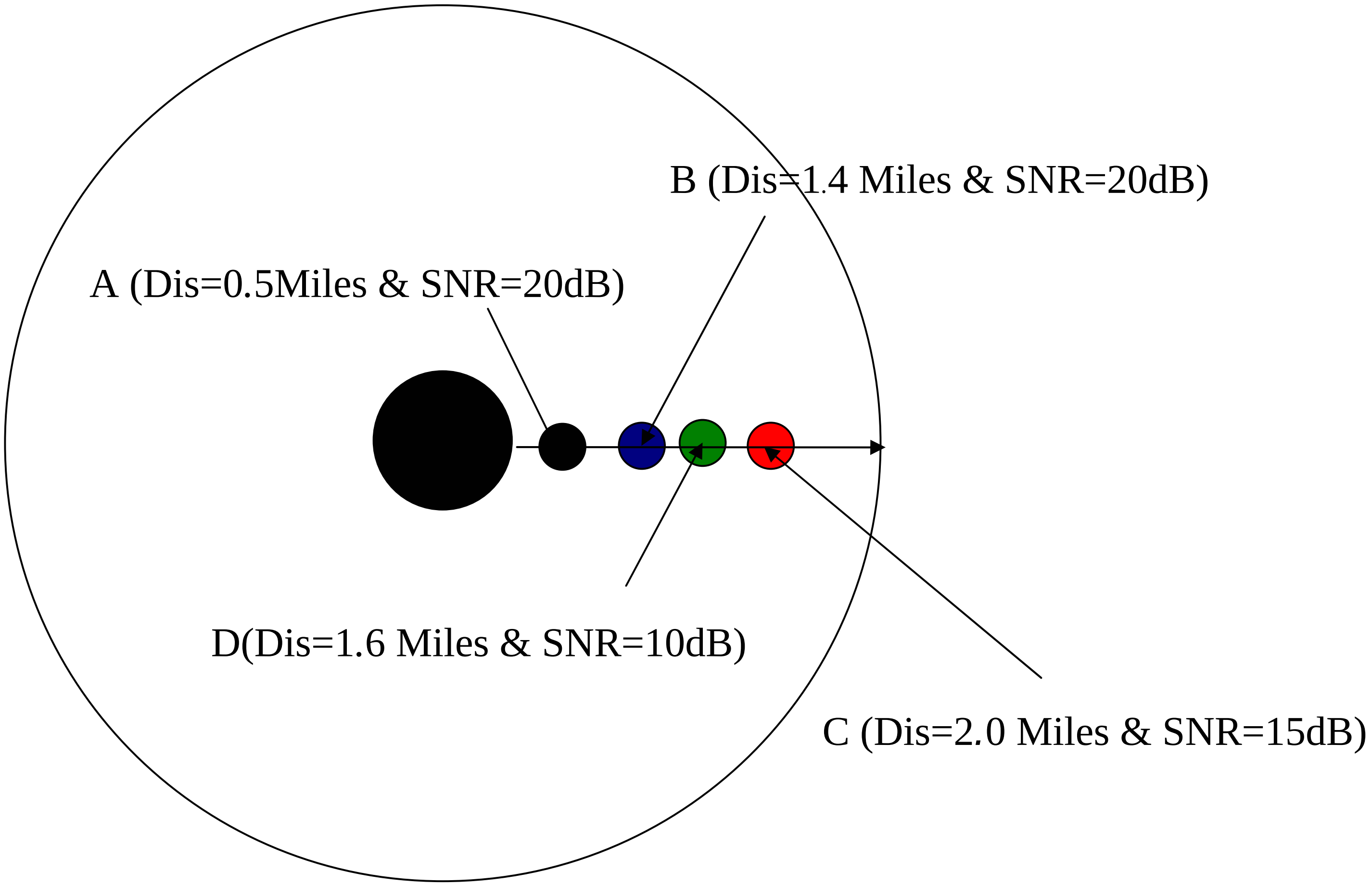






Simulation(Contd.)

- The baseline test set:



Simulation(Contd.)

- Four representative applications are chosen to run the tests:

(1) FTP UL: FTP upload of a 10 MB file

(2) FTP DL: FTP download of 50 distinct 2MB files

(3) 128 kb/s Media: A 128 kb/s media stream served from within the core network

(4) Web Page: A web page of 205 KB was periodically refreshed throughout the test (roughly every 120 seconds).

Simulation(Contd.)

- To execute the test:

  - A single load mobile was placed in an excellent SNR environment (23dB)

  - This load mobile was used to create a controlled load on the cell site.

  - The amount of load was controlled by system QoS scheduler at the base station.

  - For this QoS test case, different users traveled while performing their assigned task: Mobile#1, #2, and #3.

Simulation(Contd.)

- Test #1:

  - All users are registered to the system with equal QoS assignment. They simultaneously requested resources

  - Mobile #1, assigned QoS "Gold" user status with FTP download, has its initial throughput around 2.5*Mb/s*.

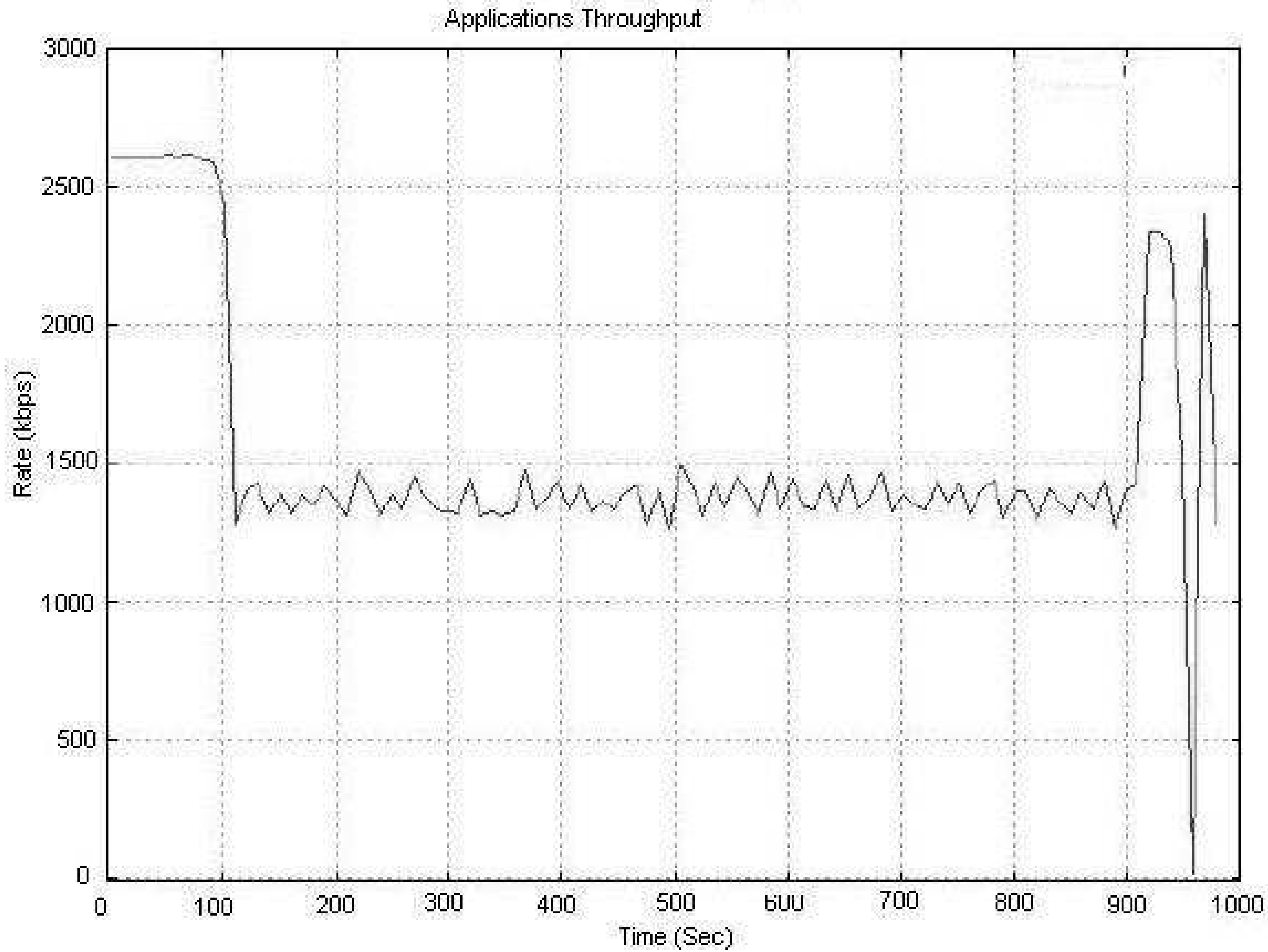
  - Then, one additional user (mobile #2), a user downloading a 128kb/s audio stream joint in, operating under poor SNR conditions

  - To maintain the sustainable data rate (approximately 160*kb/s*), the different uplink transmission options, power control, and channel coding schemes are used to offset the channel variation.

  - With only these two users active in the system, the mobile #1 is keeping the throughput at 2.6*Mb/s*

Simulation(Contd.)

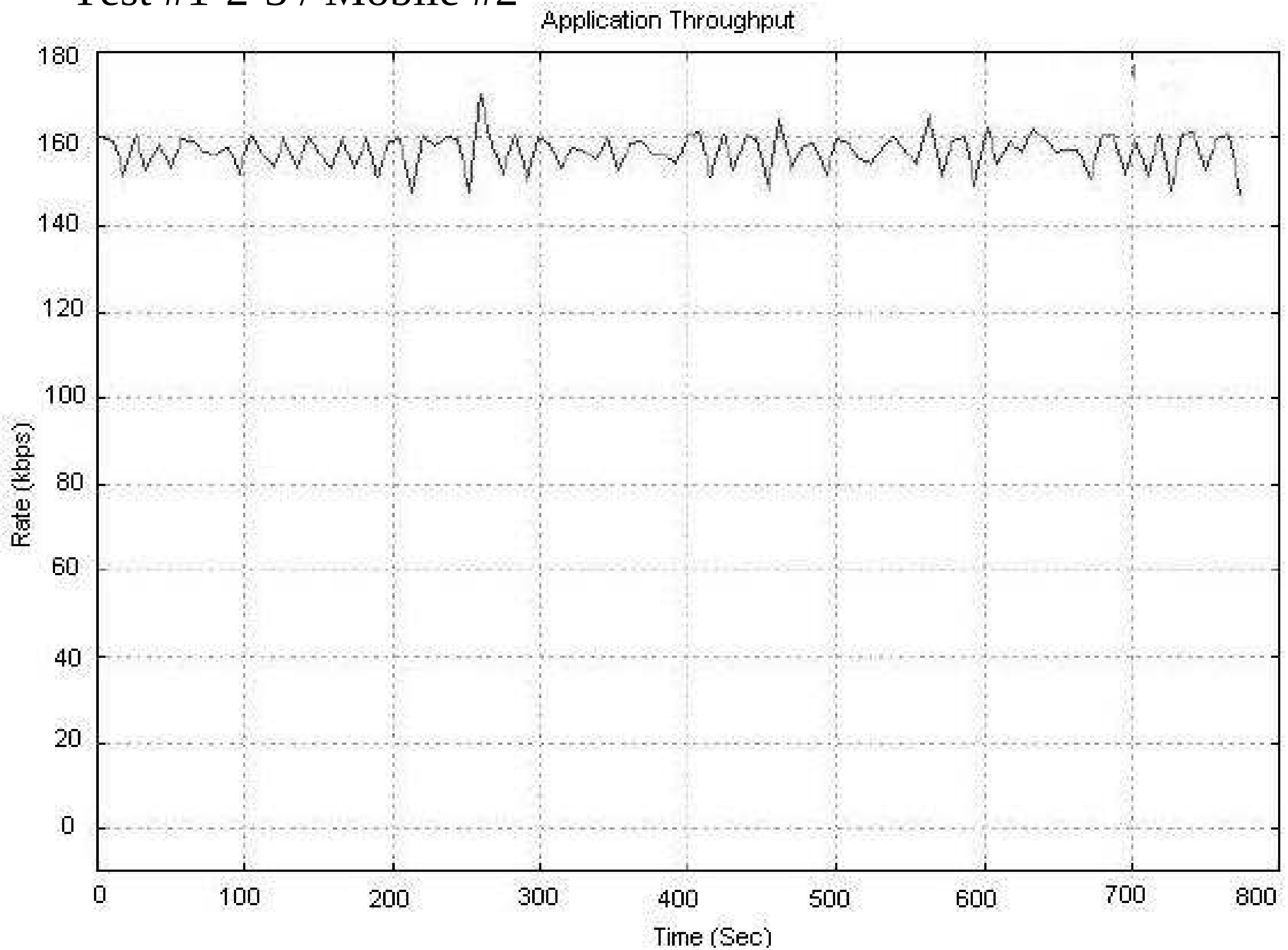
- Test #1-2 / Mobile #1



Test #2

Simulation(Contd.)

- Test #1-2-3 / Mobile #2



Simulation(Contd.)

- Test #2:

  - Illustrates the system's ability to balance the needs of diverse user request

  - After 105 seconds (t=105s), mobile #3 performing heavy load to the system (a 100MB, FTP file transfer) was introduced

  - The audio user #2 continues to receive their minimal 128*kb/s* stream, while the load #1 and FTP users #3 share the remaining bandwidth

  - The throughput of mobile #1 dropped from 2.7*Mb/s* to 1.4*Mb/s*

  - When the FTP transform (mobile #3) finished its task, the MAC scheduler instantly reallocated the excess bandwidth back to the mobile user #1, the throughput bouncing back to 2.6Mb/s.

Simulation(Contd.)

- Test #3:

  - Different QoS levels were assigned to the mobiles.

  - The mobile #1 was assigned *Bronze* QoS status.

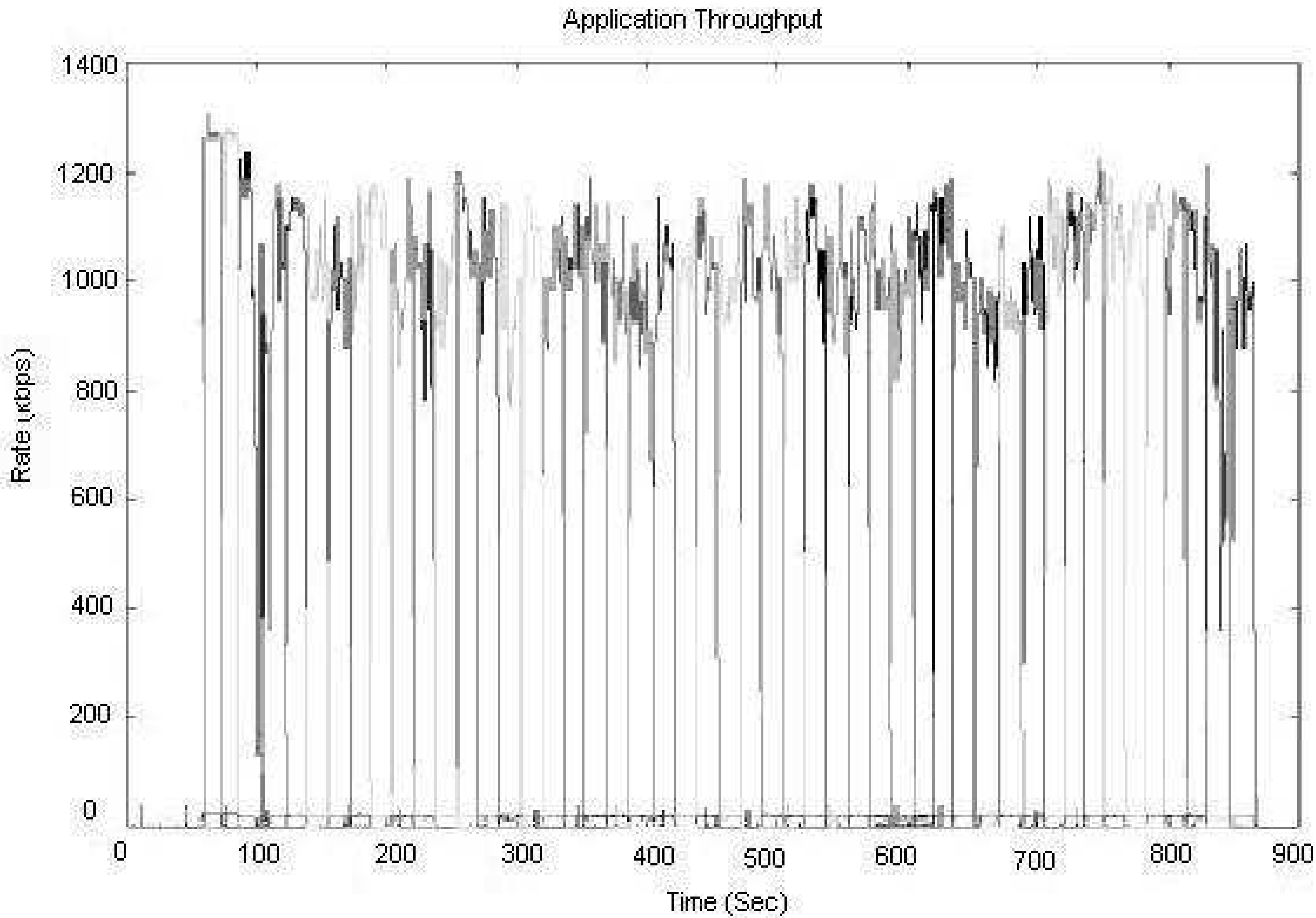
  - The Bronze QoS assignment declares that this user, regardless of cell capacity, will never receive more than 150kb/s of resource.

  - Last figure depicts the throughput drop (a step function) once the QoS designation is changed from “Gold” to “Bronze” at t = 80s.

  - The available throughput to the user was reduced from 2.6Mb/s to 150kb/s, in keeping with their new QoS assignment.

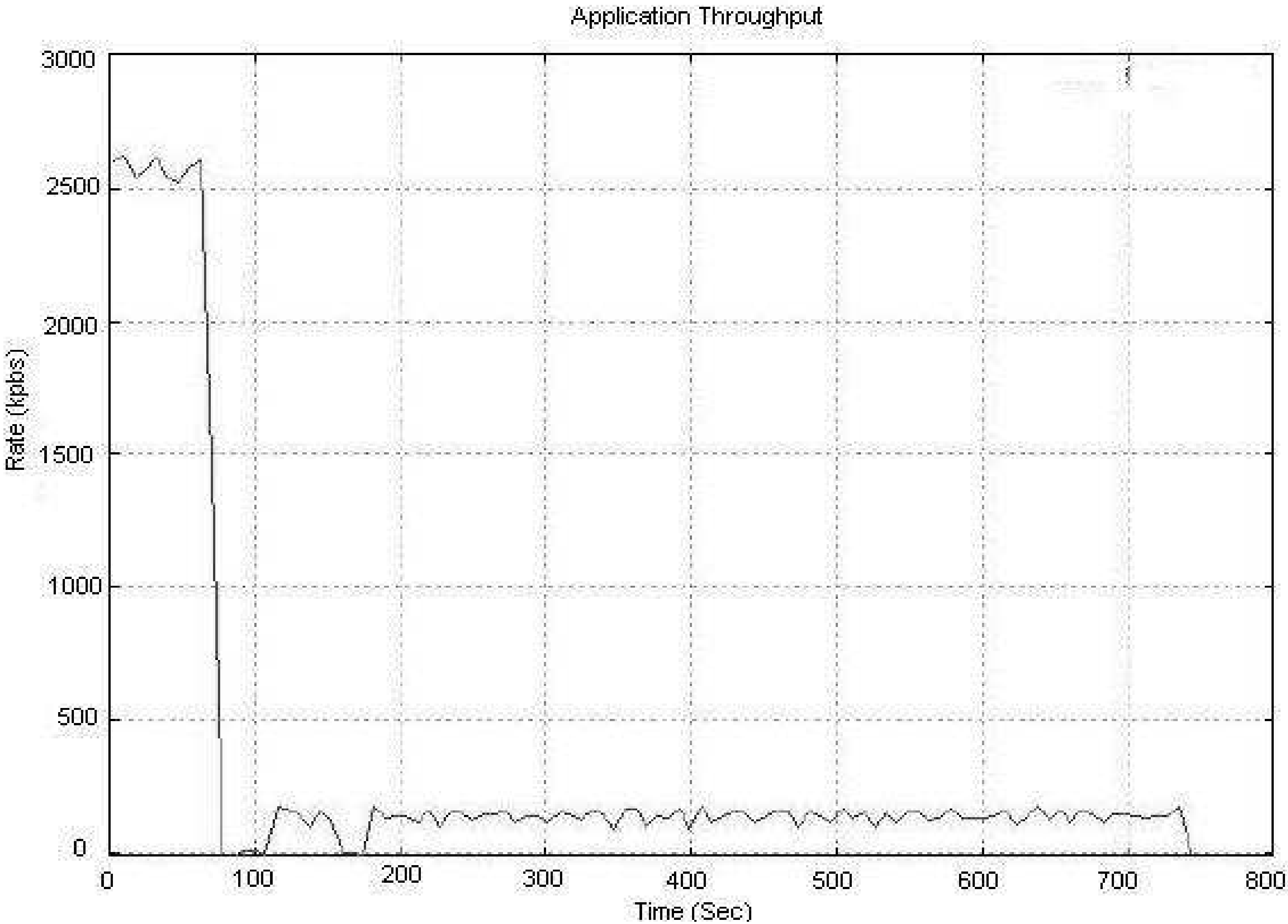
Simulation(Contd.)

- Mobile #3



Simulation(Contd.)

- Test #3 / Mobile #1



Test #3

Conclusion

- A cross-layer design scheme is proposed for wireless QoS content delivery, among MAC and physical layer.

- Central to the proposed cross-layer design is the concept of *"adaptation"*.

- The proposed QoS-awareness scheduler and power adaptation scheme at both uplink and downlink MAC layer coordinate the behavior of the lower layer (physical layer) for resource efficiency.

References

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Questions?