NYU POLYTECHNIC SCHOOL OF ENGINEERING

CENTER FOR ADVANCED TECHNOLOGY IN TELECOMMUNICATIONS

Streamloading:

Low cost high quality video streaming

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(joint work with Amir Hosseini and Fraida Fund)

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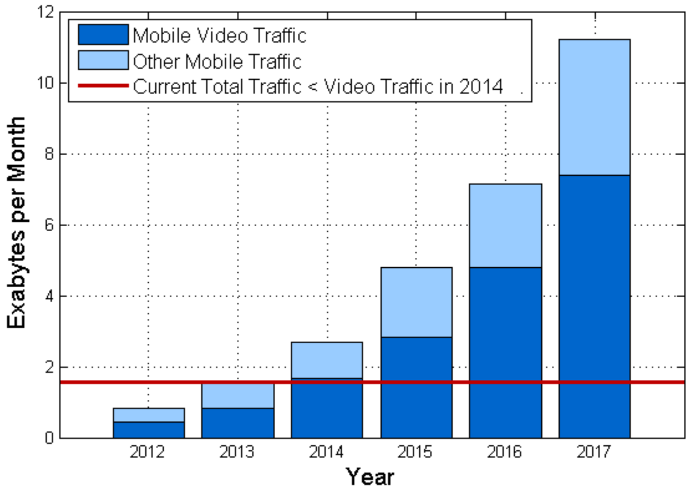
Modern Cellular Networks

- Evolution of modern cellular networks:
  - Exponential increase in data consuming applications. (Smartphones)
  - Manifold increase in capacity. (3G /4G LTE/4G LTE Advanced)
- Cisco predicts cellular data traffic to grow over **eight times** in the next **four years**.
- Over two-thirds of cellular data traffic consists of video.
  - Video traffic next year is projected to exceed current total traffic.
  - Major portion of video traffic is contributed by video streaming services.



Traditional Video Delivery

Streaming Video Service	Downloaded Video Service
NETFLIX hulu	YouTube iTunes
Downloads only a small number of future chunks irrespective of the available bandwidth.	Downloads aggressively, as many future chunks as allowed by bandwidth available.
Content owners provide this at a cheaper price to subscriber.	Services are more expensive to subscriber.
Subscriber can watch the video only with an active internet connection.	Subscriber can watch the video any time, any place.
Desirable to users, from a price point of view.	Desirable to users, from a video quality point of view.

Scalable Video Coding

- Modern cellular users now watch high quality videos on their mobile devices.
- Wireless networks (3G/4G LTE, WiFi, etc.) inherently provide variable bandwidths to users.
- Scalable Video Coding (SVC):
  - Extension of H.264 video coding standard, also part of HEVC
  - Allows lowering of video quality at low available bandwidths.
  - Divides the video into a Base Layer, and several Enhancement Layers.
  - Base Layer can be decoded by itself, provides for lowest quality video.
  - Enhancement layers progressively improve video quality, and can be decoded only when all lower layers are available.
  - In the absence of Base Layer data, any amount of Enhancement Layer data is useless.

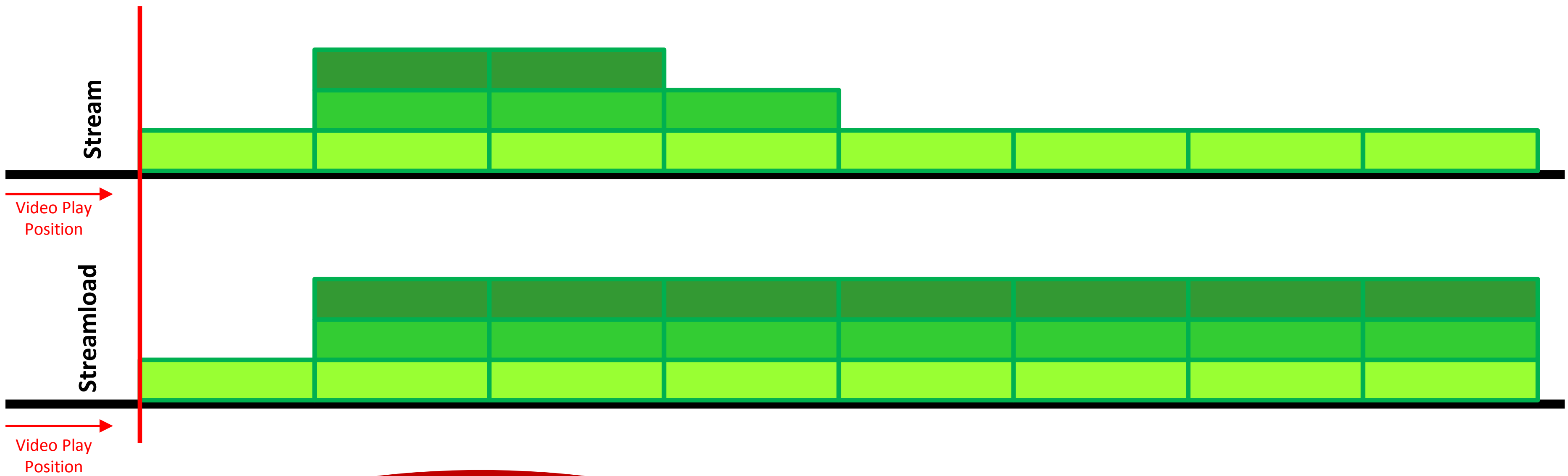
Limitations of Streaming

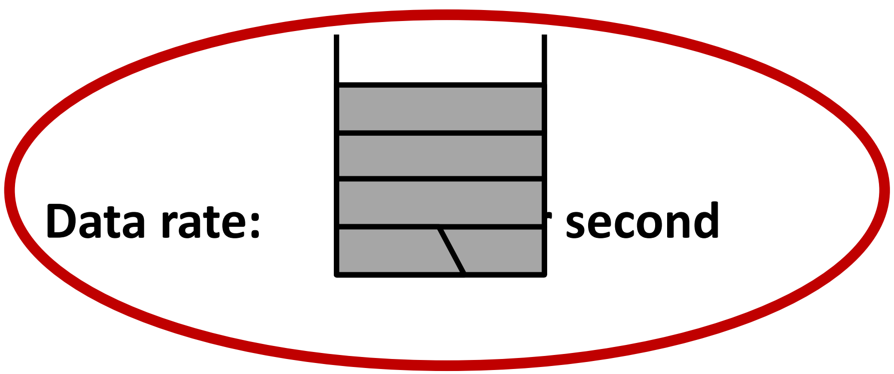
- When user is close to base station:
  - High available bandwidth.
  - Not allowed to download future chunks of video (unlike downloading).
  - Surplus bandwidth goes unused.
  - Enjoys high quality video only for the time being.
- When user moves away from base station:
  - Available bandwidth drops.
  - Quality of video drops almost instantaneously.
- Need of the hour: A video delivery service…
    - that potentially provides for download quality video,
    - but legally qualifies as a video streaming service.

Video Streamloading Service

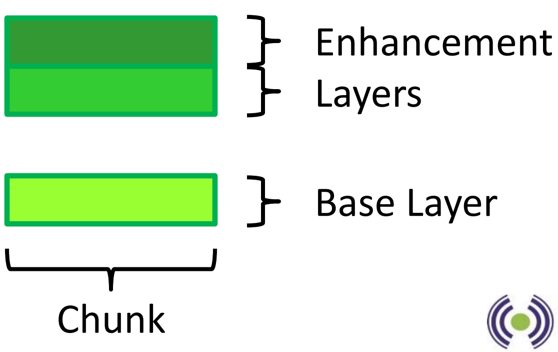
- Streamloading:
  - ***Downloads*** Enhancement Layers - Allow users to aggressively download any number of future enhancement layer video chunks
  - ***Streams*** Base Layer - Restricted download of future base layer chunks.
  - Legally qualifies as streaming, allowing streaming service level pricing.
  - Takes advantage of surplus bandwidth, allowing downloading service level video quality.
  - It may also reduce your data charges!

Streamloading Illustration





Dropping with time



Other, equally compelling, use cases:

- Video service provider payments to core ISP: Typically charged by *peak usage*, not average. Streamloading can reduce this peak significantly.
- Cable/FiOS/U-verse/satellite can reduce their distribution network capital expenditure costs by reducing peak usage; streamload to set-top box under their control.

Why not download encrypted videos and stream the decryption keys?

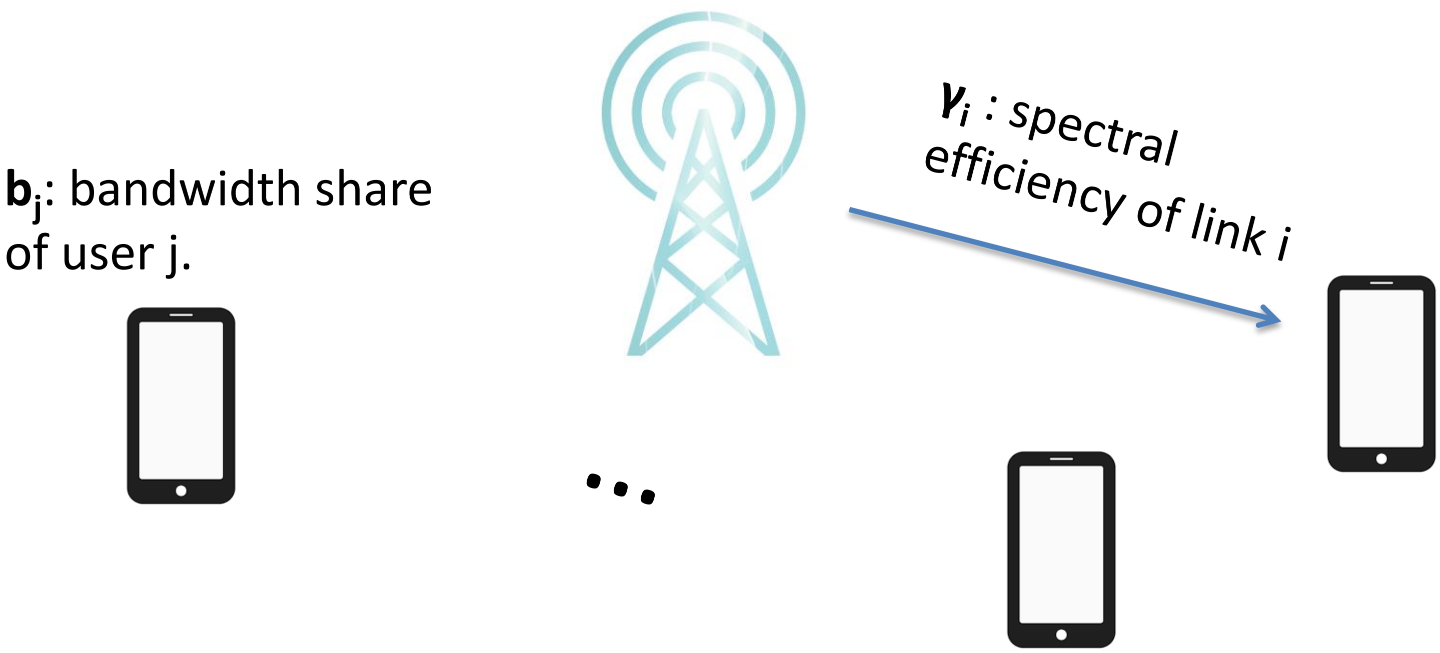
- Legally, this would still be considered a download

Problem Formulation

(joint work with Amir Hosseini and Gustavo de Veciana's group)

Consider a network with **N** users, each having a video streamed from the access point.

W: Total available bandwidth



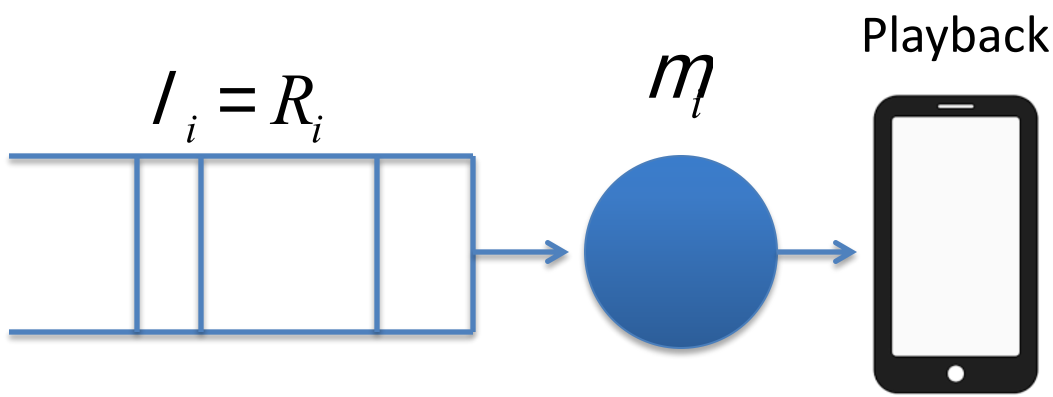
Problem Formulation

Capacity Constraint:

$$\sum_i b_i \le W$$

Rate allocated to each user at time **t**:

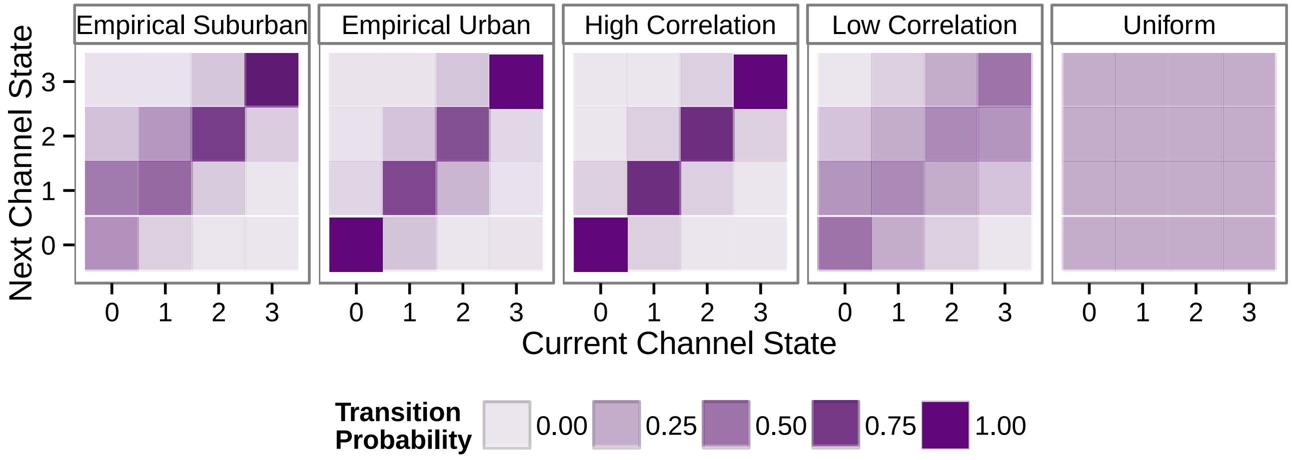
$$R_i(t) = \gamma_i(t) \times b_i(t)$$



- $E(\mu_i)$ is an indicator of video quality and should be maximized.
- The buffer should never become empty to avoid re-buffering.

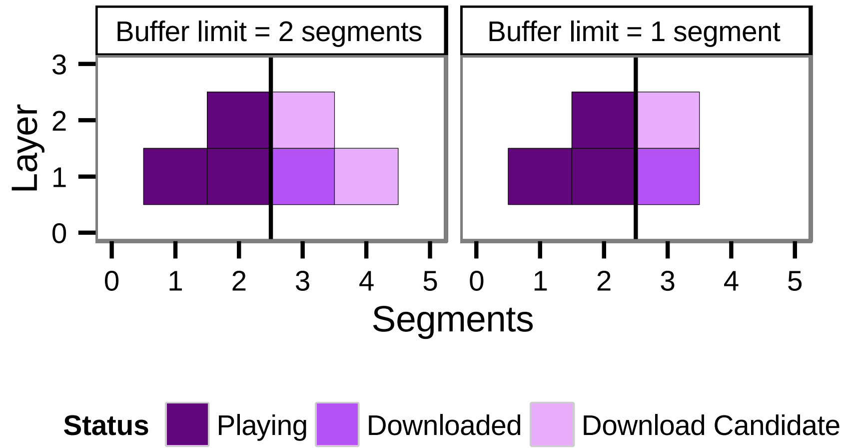
Environment Characteristics

- A wireless channel varies differently with time in different environments.
- The variation pattern can be modeled as a Discrete State Markov Chain.



Buffer limit

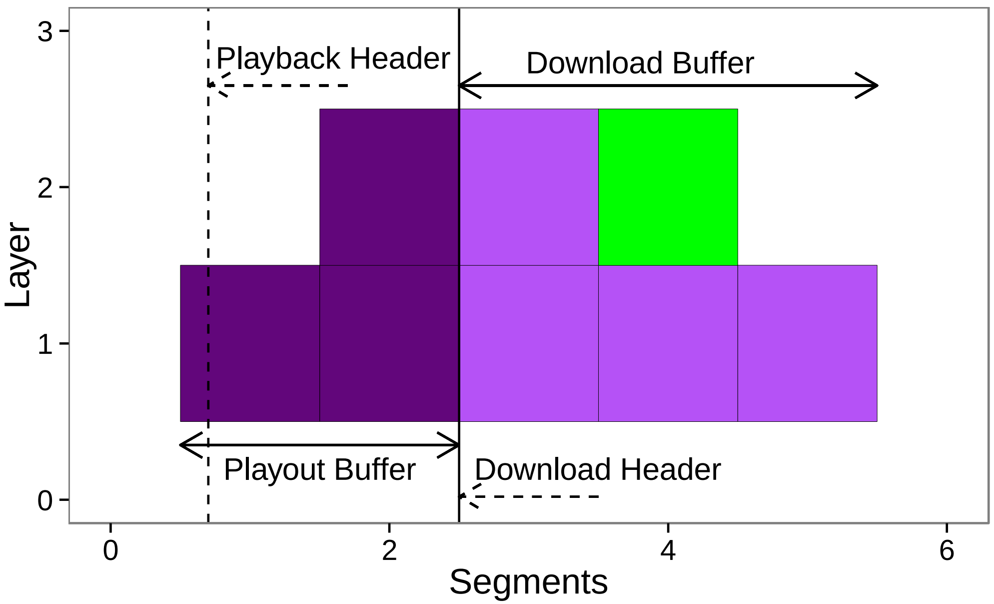
- Content providers use different limits on how much users can buffer video ahead of playback.
  - Small buffers cause poor video quality
  - Large buffers cause bandwidth wastage due to abandonment, or violate memory restrictions on mobile device.



- Limiting the buffer also restricts the possible download choices.

Dynamic Programming Model

- We formulate the SVC download policy using a Semi Markov Decision Process (SMDP) with the following parameters:
  - 2 Layers, each 1Mbps
  - Wireless channel has four states with {0.5,1,2,4} Mbps data rate.



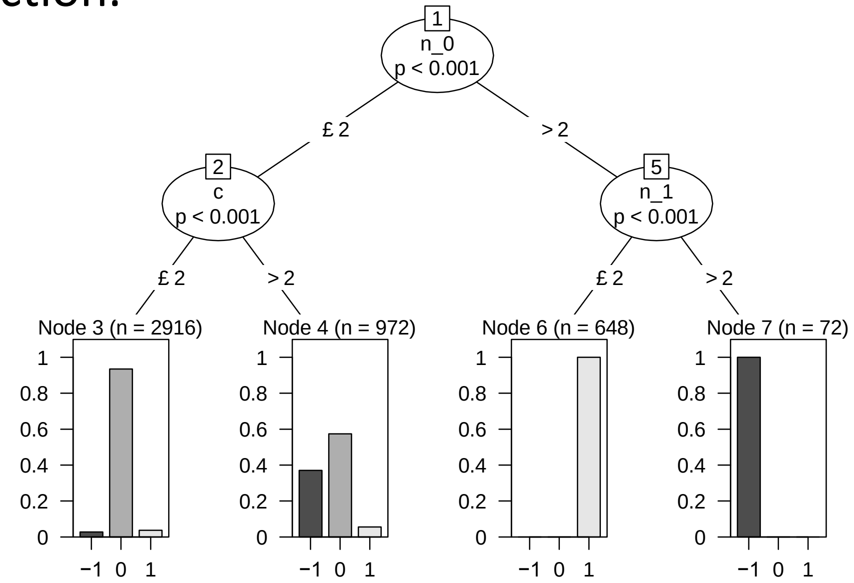
State Space attributes:

1. Instantaneous channel state
2. Location of the playback header
3. Number of segments for each layer in download/playout buffer

Action:
Which Layer to download for the next available segment

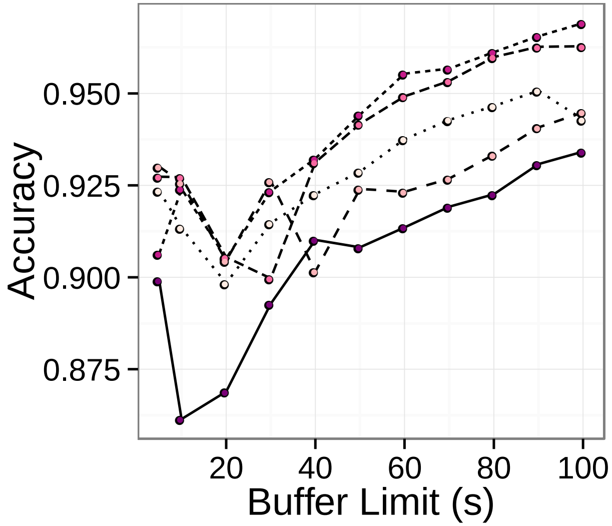
Decision Tree Classifier

- We ran the SMDP for all channel models and buffer limits ranging from 5s to 100s.
- The output of the SMDP is a vector of state attributes and the corresponding action.

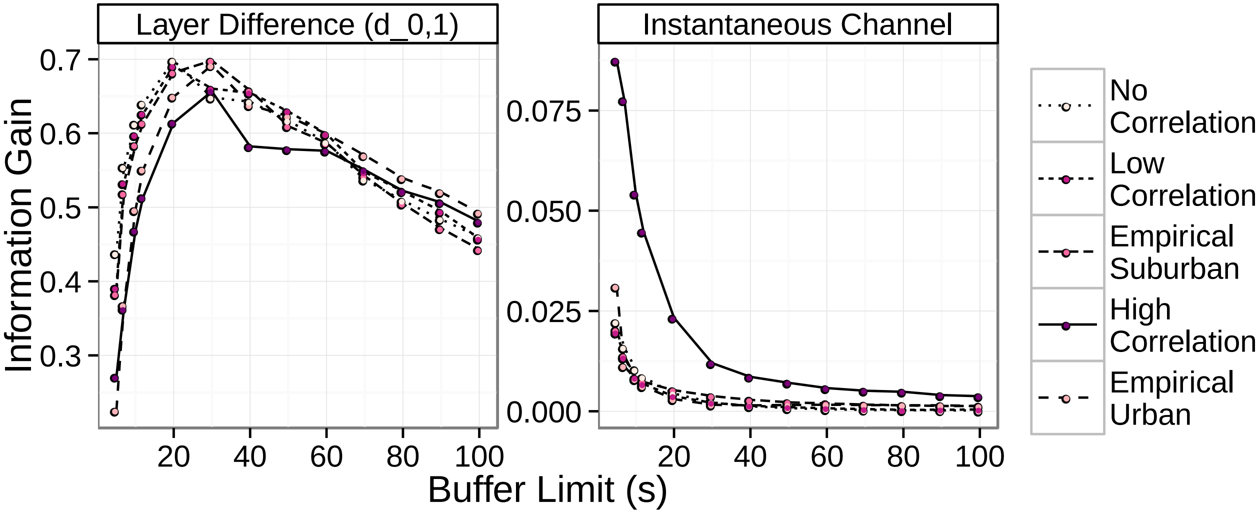


- Using the decision tree algorithm, we classify the states based on the most determining and impactful attribute in order to design and adapt policies.

Results



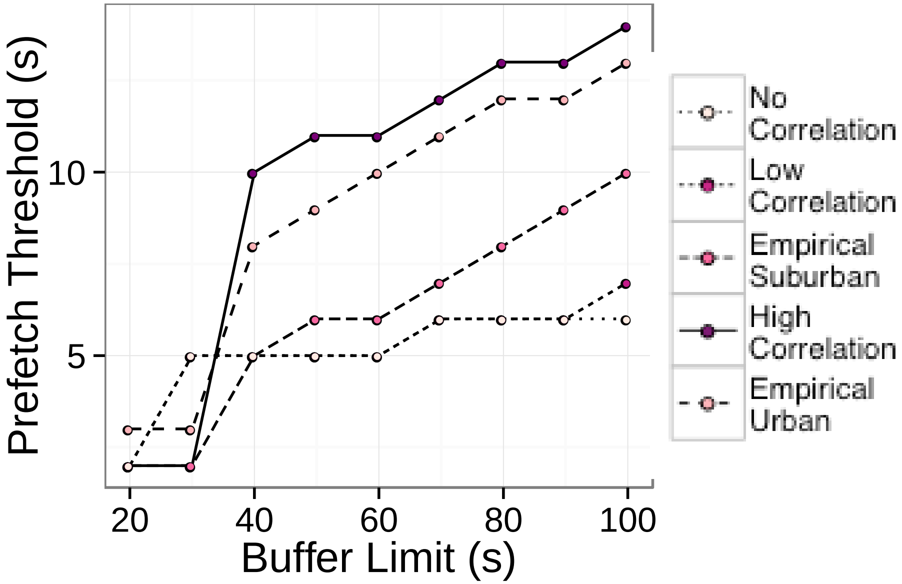
The classifier predicts all cases with more than 87% accuracy.



The difference between the number of base and enhancement layers in the buffer (layer difference) is much more significant in decision making than instantaneous channel state

Results

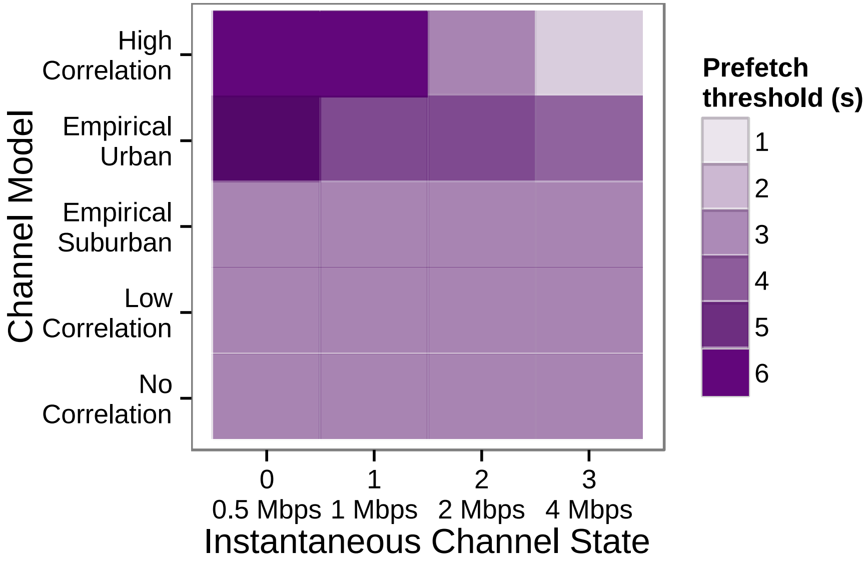
- The download policy in all cases is mostly based on prefetching base layer and backfilling enhancement layers.
  - If the layer difference exceeds a threshold, the policy changes from prefetching to backfilling



Higher correlation results in higher threshold, thus, more conservative download policy

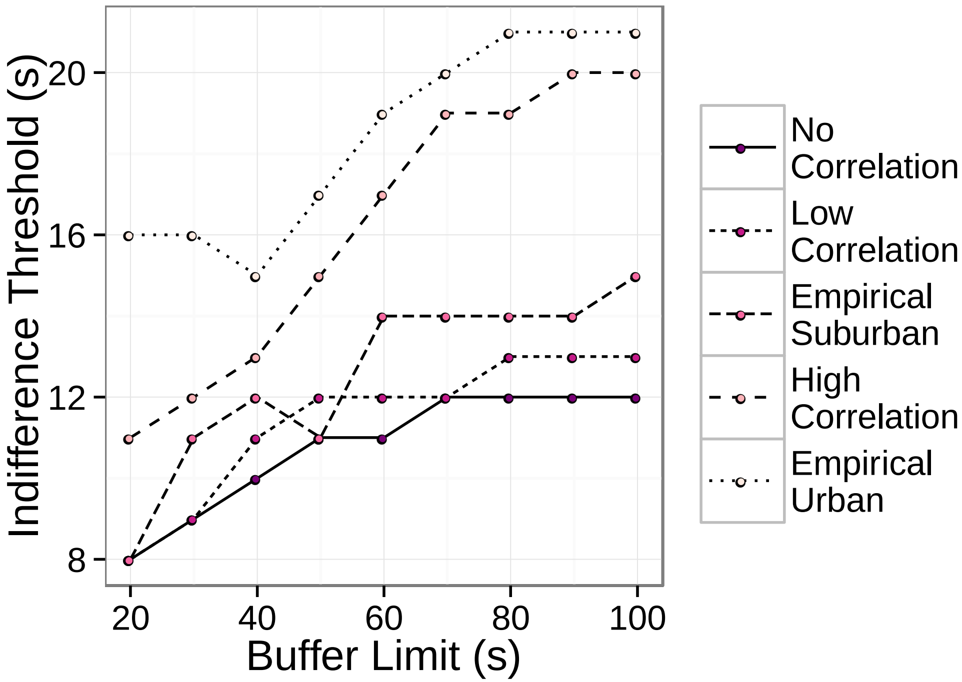
Results

- Unlike for large buffer limits, if the buffer limit is 5 or 10 seconds, the instantaneous channel state becomes determining but only in highly correlated channels.
  - If correlation is high, act more greedily in good states and more conservatively in bad states.
  - If correlation is low, instantaneous channel states is unimportant.



Results

- When download buffer fills up to a certain threshold, the policy becomes indifferent to which layer to download.

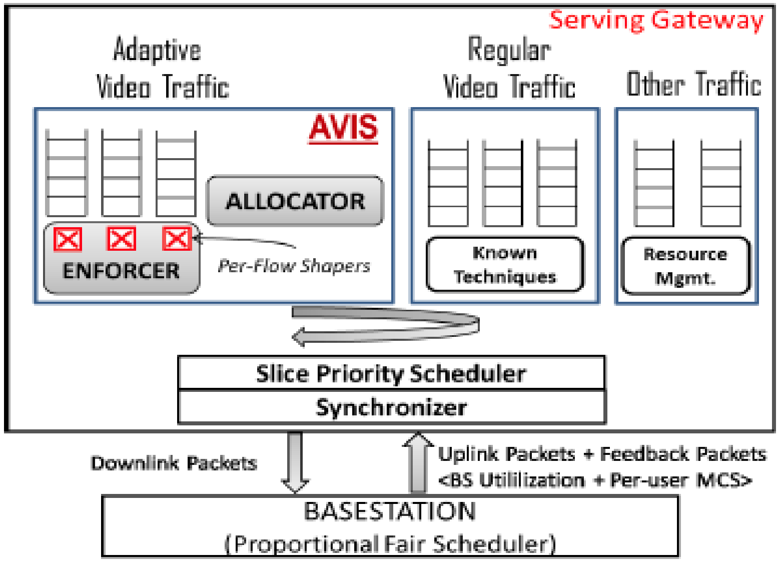


Conclusions

- SVC download policies can be expressed as a simple set of rules which should adapt themselves to the channel characteristics and buffer restrictions.
- Occupancy of download buffer is more important in decision making than instantaneous channel state.
- In slow varying channels, the download policy is more conservative than in fast changing channels.
- Instantaneous channel state becomes important for small buffer limits and slow varying channels.
- Policy becomes indifferent after filling enough segments into download buffer.

Scheduling Adaptive Video over Cellular Networks

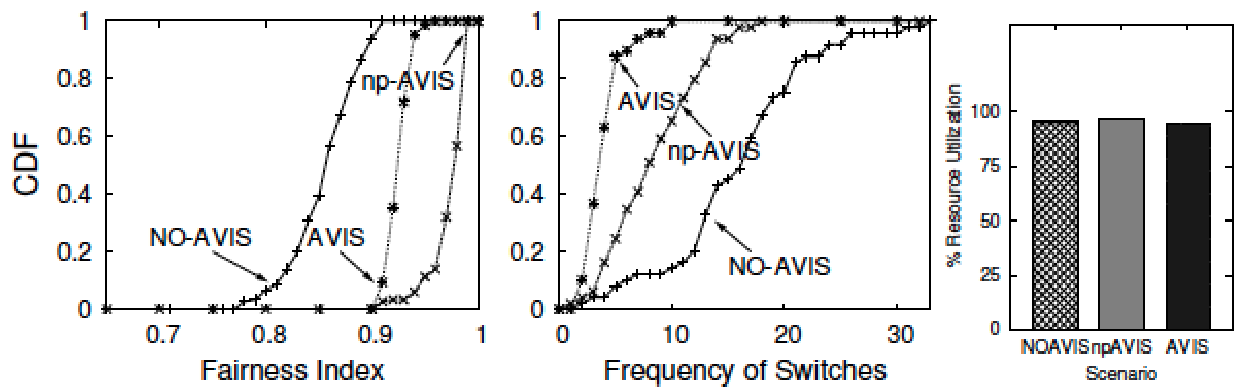
- As network grows, using appropriate resource allocation becomes crucial.
- Current base stations are doing a relatively poor job in meeting major requirements of reliable video delivery to multiple users:
  - fairness
  - bit rate stability
  - high utilization
- AVIS is a proposed scheme for gateway level resource allocation for adaptive video traffic with minimum dependence on cellular technology.



Chen, Jiasi, et al. "A scheduling framework for adaptive video delivery over cellular networks." Proceedings of the 19th annual international conference on Mobile computing & networking. ACM, 2013.

Scheduling Adaptive Video over Cellular Networks

- AVIS proves to outperform conventional scheduling mechanisms in terms of fairness and bit rate stability.
- Penalizing or not penalizing bit rate changes provides a tradeoff between stability and fairness.
  - Human perception of bit rate changes in video is still a hot research topic.



(a) Fairness (b) Stability (c) Utilization

np-AVIS does not penalize bit rate switching.

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Channel Dependent Pricing for Video Delivery to Mobile Users

Channel Dependent Pricing

- In a wireless network, user located in poor channel conditions use up more channel resources.

Link Quality	MCS	Efficiency (bps/Hz)
Best	64QAM 5/6	5
Worst	QPSK 1/2	1

- If users agree not to request video segments in poor channel states, overall bandwidth efficiency increases:
  - There is no incentive to do that!

Fund, Fraida, S. Amir Hosseini, and Shivendra S. Panwar. "More bars, more bang for the buck: Channel-dependent pricing for video delivery to mobile users." Computer Communications Workshops (INFOCOM WKSHPS), 2014 IEEE Conference on. IEEE, 2014.

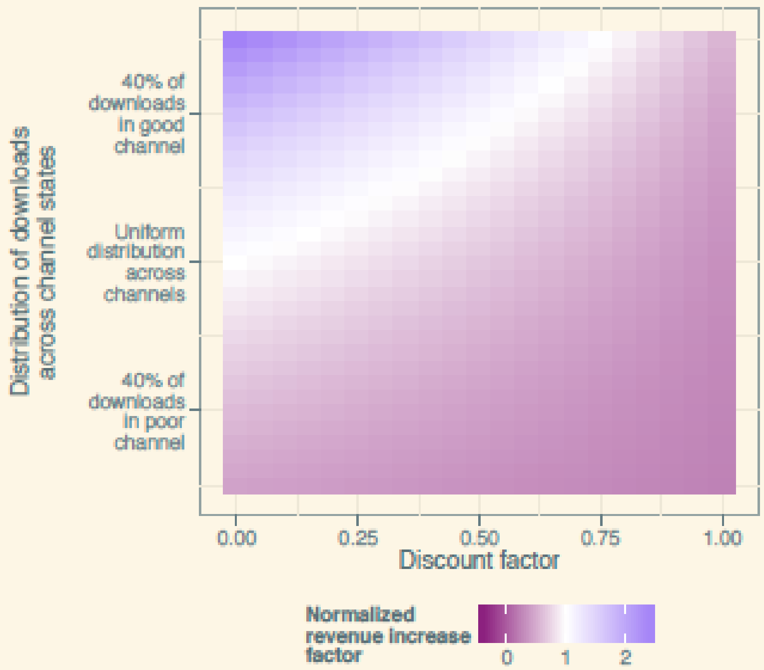
Channel Dependent Pricing

- Network Operators can offer incentives for users to change their usage.
  1. Each user is given a monthly quota for video download based on the overall data plan price.
  2. If in a good channel state, users pays less from their quota for downloading a segment than in bad states, i.e. they get discounts by downloading in better channel states.
  3. Due to time elasticity of video, users might refrain from downloading to wait for a better channel.

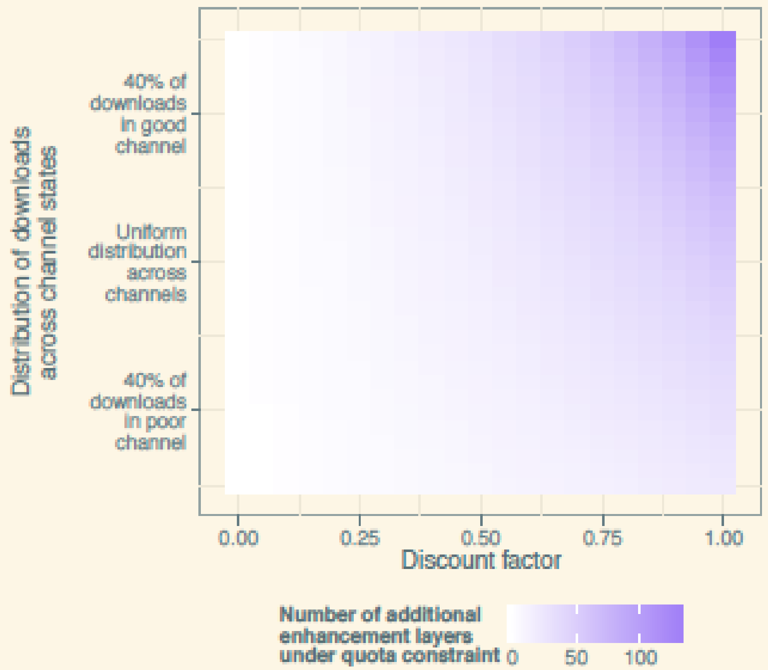
- The more users postpone their requests, the higher the spectral efficiency.
  - Network Operator benefits from serving more users.

Channel Dependent Pricing

For what kind of pricing are users and carriers willing to participate?



Service Provider

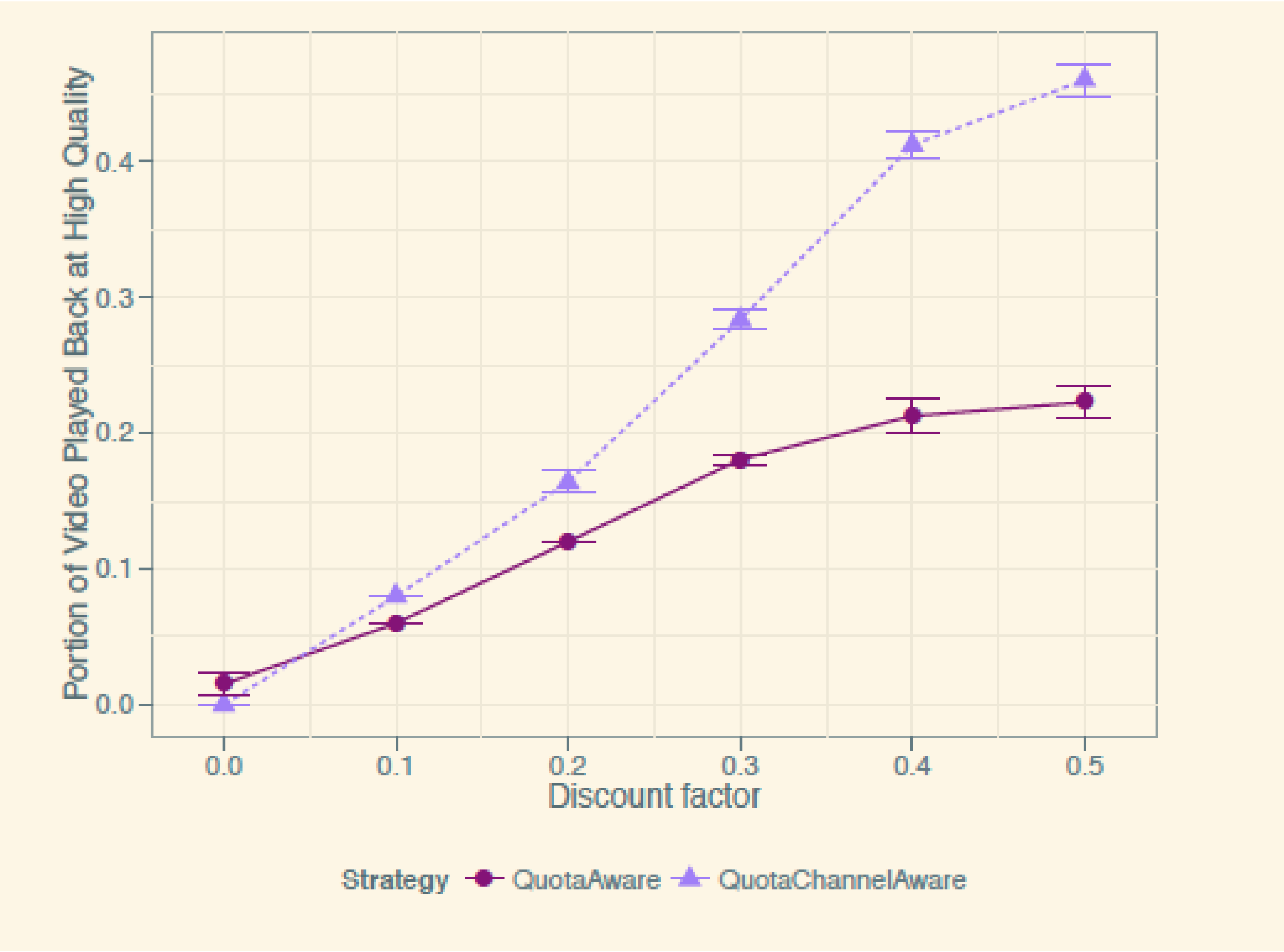


User

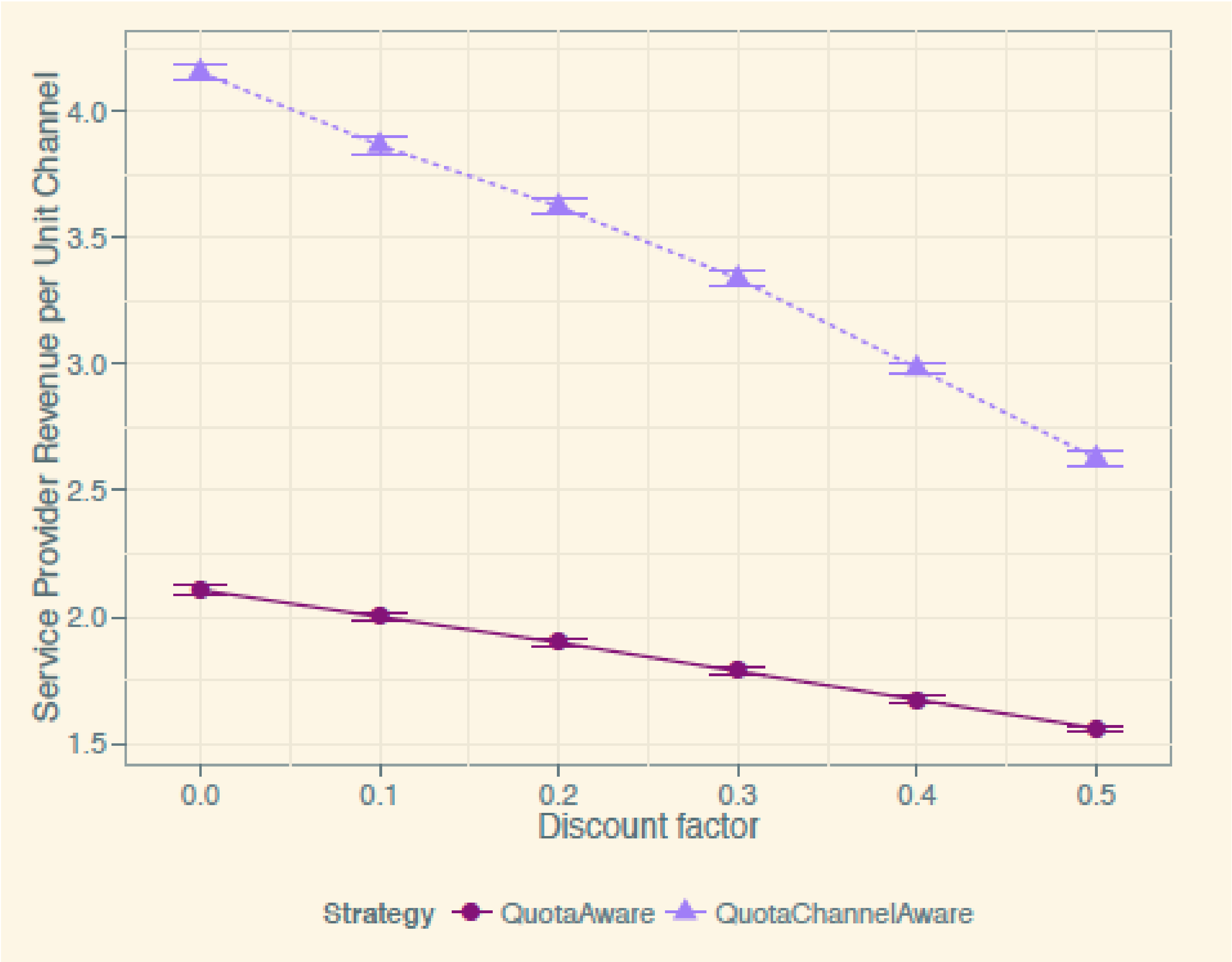
Channel Dependent Pricing

- For each discount value, determine the pricing in each channel state.
- Different strategies for video download are used to analyze the revenue earned by each of the two entities.
  - **Quota aware strategy:** Users decide on how to request video solely based on the remaining quota.
  - **QuotaChannel aware strategy:** Users decide on how to request video by considering both channel state and the remaining quota.

Channel Dependent Pricing



Channel Dependent Pricing



Conclusion

- Video, video streaming in particular, is going to be the dominant application (by bandwidth) in the wireline and wireless Internet
- How it is implemented and priced can reduce its cost to consumers
- Streamloading is one such option that can offer download quality at streaming cost, while reducing the load on the network, which may in turn further reduce the cost to the consumer