EnDASH-A Mobility Adapted Energy Efficient ABR Video Streaming for Cellular Networks

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A Typical Scenario

Pretext

- Online video streaming - most popular mode of entertainment
- Online mobile video traffic - 71% in total mobile traffic volume
- Video experience over mobile Internet negatively affected by
  - Poor mobile connection quality
  - Fall back to legacy networks
  - Excessive Battery Drainage - increases under mobility
    - Incessant network scanning
    - Handovers

Our proposed solution: EnDASH – A mobility adapted energy efficient video streaming algorithm for cellular networks

UE Energy Consumption Model – 4G LTE

- Understanding the energy/power consumption model and RRC state machine of 4G LTE
- Radio Resource Control (RRC) – Radio Resources are time-frequency resources in LTE

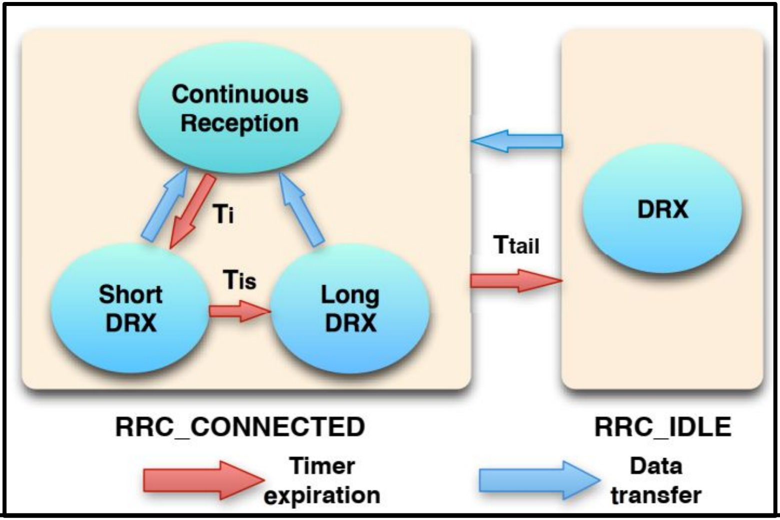


Fig: RRC state machine of 4G LTE[1]

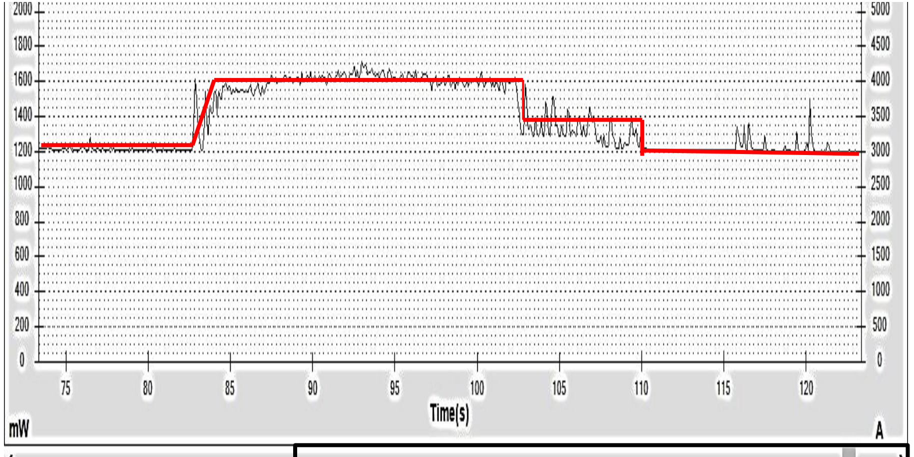


Fig: Measured Power data for downloading a 1Mb file

1. Junxian Huang, Feng Qian, Alexandre Gerber, Z. Morley Mao, Subhabrata Sen, and Oliver Spatscheck. 2012. A close examination of performance and power characteristics of 4G LTE networks. In *Proc* MobiSys '12 ACM, New York, NY, USA, 225-238.

Pilot Study

Our Goal : Energy optimization at end devices based on Intelligent Traffic Scheduling

1. Profiling the end user device energy consumption as a function of fluctuations in the network conditions
2. Understanding the correlation between traffic generation pattern and energy consumption

PILOT STUDY: Extensive throughput and energy measurements based carried out

- In different mobility conditions - Stationary, slow-moving electric vehicle, cars in the highway, cities,
- In different geographic locations - Kharagpur, Kolkata, Guwahati, Bangalore, Malda

Experimental Set-up

- **Equipment Used:**
  - Monsoon Solutions Power Monitors
  - Smartphones - Moto G5, Micromax Canvas Infinity
- **Service Providers** - Airtel, JIO, Vodafone

- **Software Set-up:**
  - Network data collected - NetMonitor Lite app
  - GPS location and Speed - GPS logger
  - File download throughput - tcpdump
  - HTTP client-server program set up using smartphone and Amazon Web server
  - Video Streaming Apps - YouTube, Netflix, Amazon Prime, SonyLiv

A total of 39662 seconds of valid data point, collected over a period of 11 months

Observations

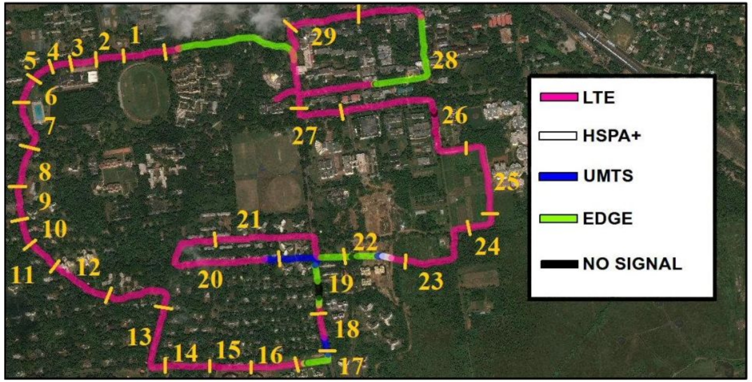


Fig: Trajectory of Moto G5 connected to Airtel inside IIT Kharagpur campus. Networks : 4G, HDPA, UMTS, EDGE.

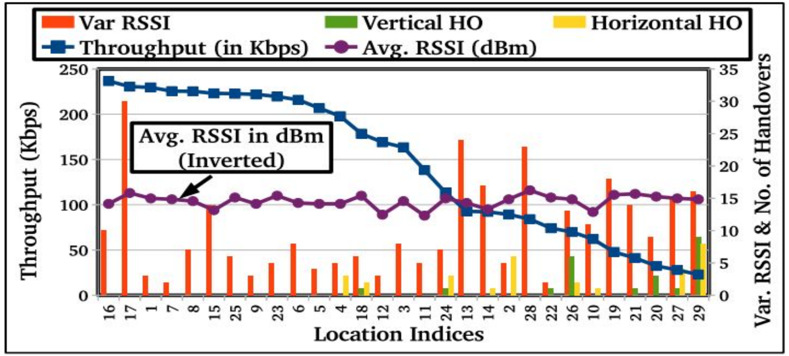


Fig: Sorted thpt across 29 stretches. Variations with RSSI, Vertical and Horizontal Handovers

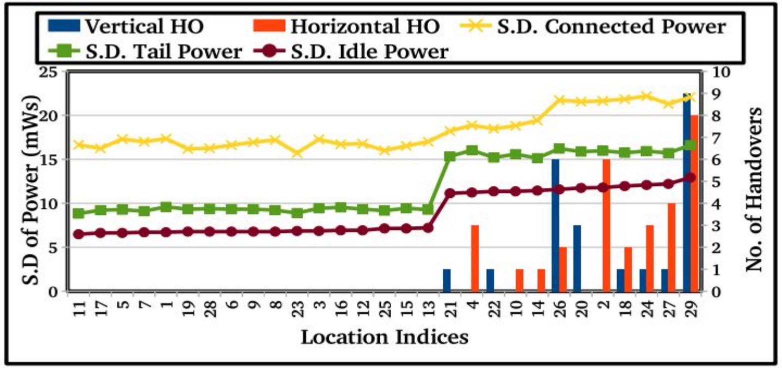


Fig:Variance of Power Consumption with RSSI, and Vertical and Horizontal Handovers

Takeaway 1: The wireless network condition is best quantified by throughput which depends significantly on phenomena such as handovers and not on received signal quality alone.

Observations

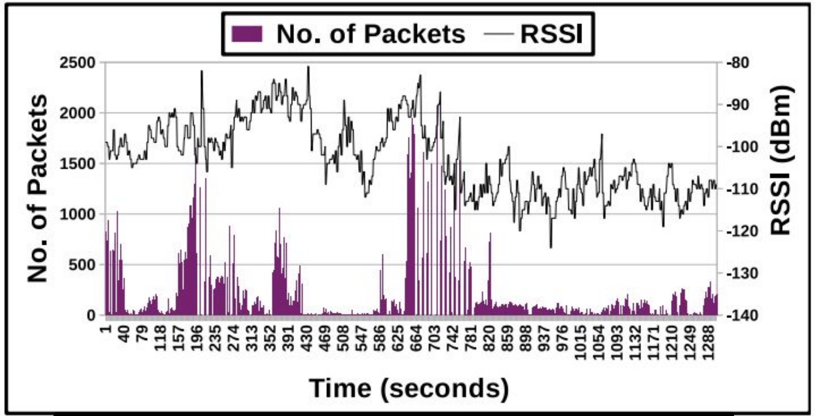


Fig: Packet trace of a 360p Youtube video download with the temporal variation in the RSSI during the download

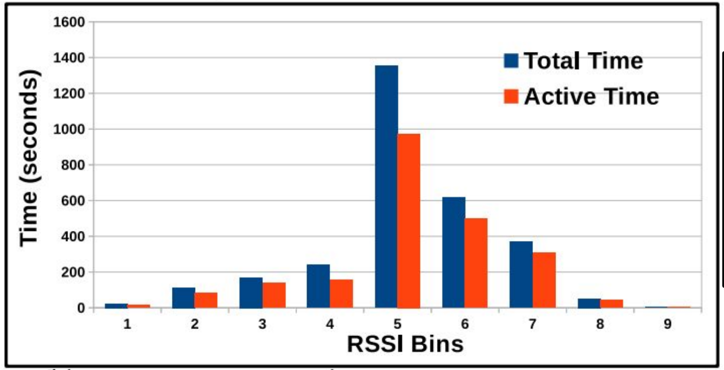


Fig: Total time spent in each RSSI bin and the active time in each bin

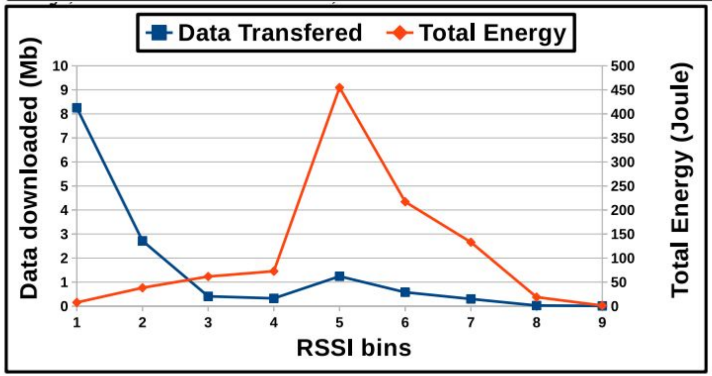


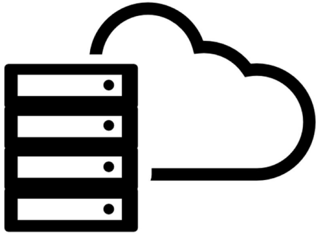
Fig: Amount of data downloaded and Power Consumption in each RSSI Bin

Takeaway 2: The current protocol of video download attributes higher weightage to the playback-buffer length than the user's instantaneous received signal strength or throughput.

EnDASH – To improve energy efficiency

- Fetching data during good channel conditions can reduce total download time
- Reduced dwell time in CONNECTED RRC state - less power consumed.

DASH - Bitrate Adaptation



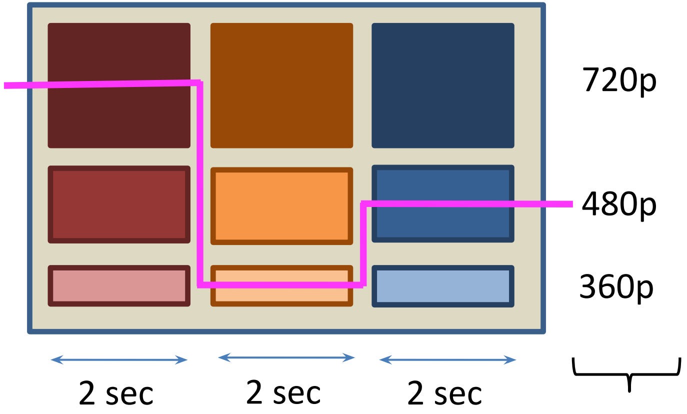
Video Server

Request:
next video chunk at bitrate ***R***

Response:
video chunk at bitrate ***R***

Video Client

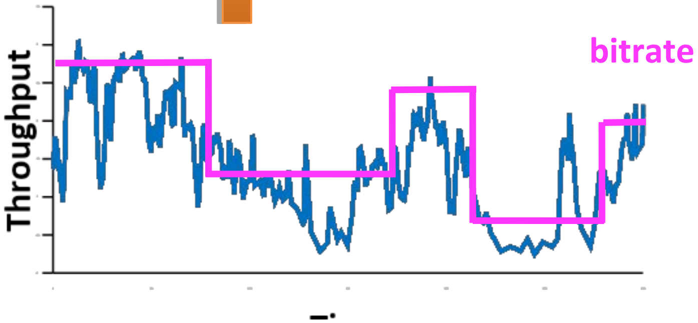
Client decides bitrate ***R*** of next chunk based on network conditions



Playback time

Resolution ~ Bitrate

Adaptive Bitrate (ABR) Algorithms



EnDASH – To improve energy efficiency

- Fetching data during good channel conditions can reduce total download time

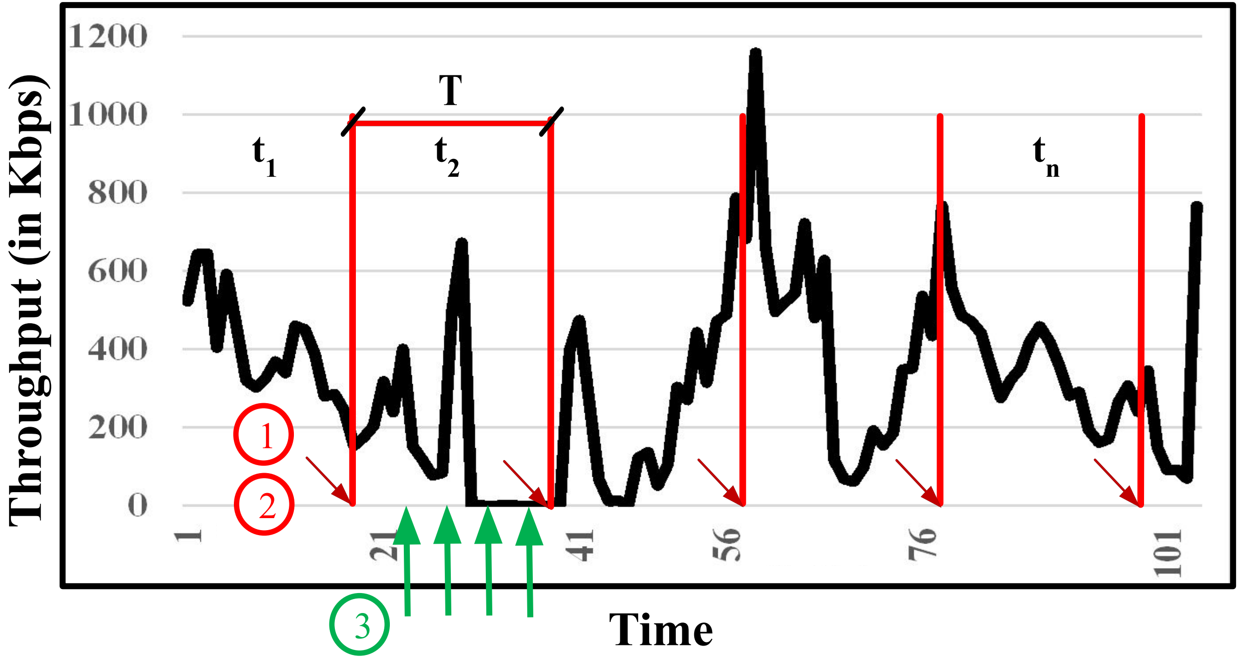
- Reduced dwell time in CONNECTED RRC state - less power consumed.

To be achieved through the following:

- Tuning buffer length to the perceived throughput
    - **Advantage**: Allows downloading higher volume of video chunks during good channel conditions while in motion
- Adapting the bitrate to the perceived throughput
    - **Advantage**: Unhindered Quality of Experience (QoE)

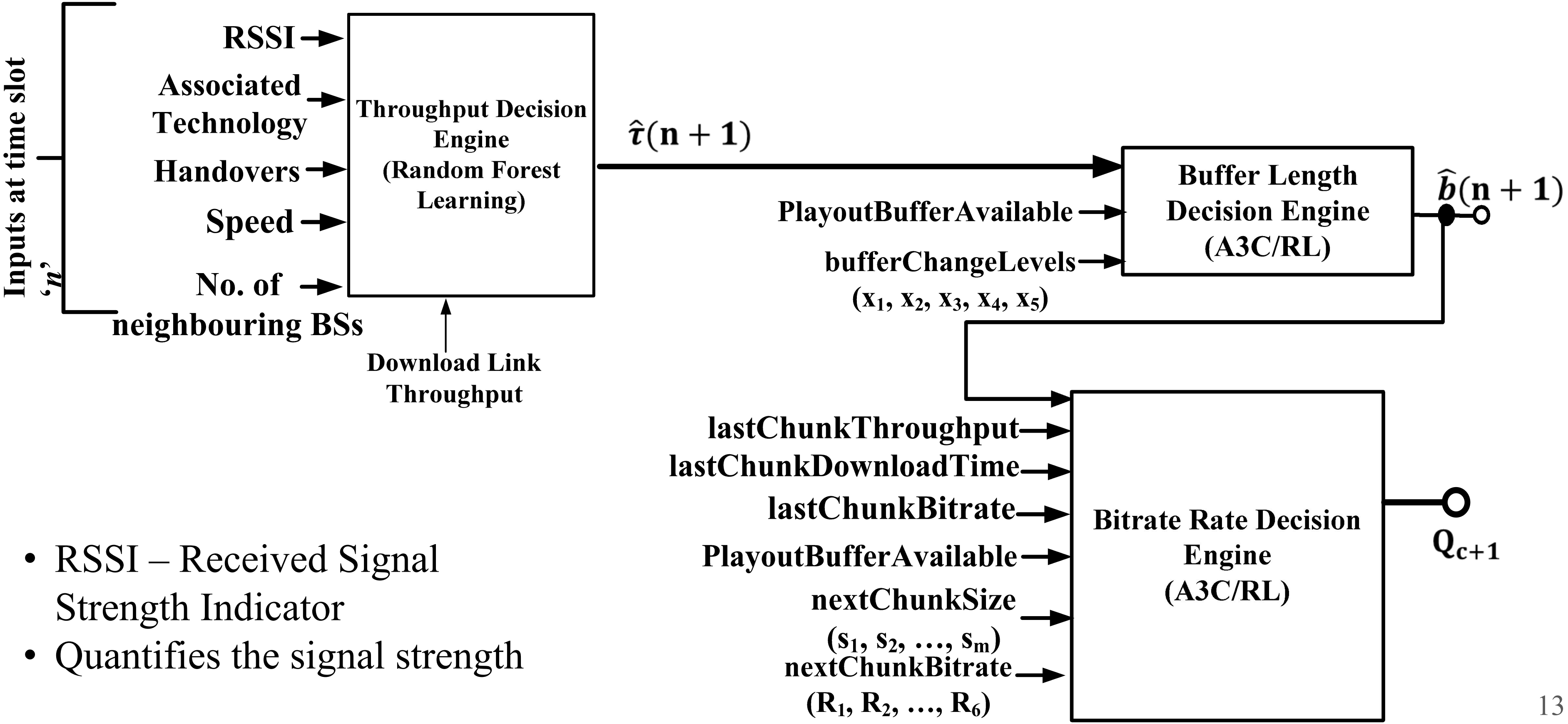
USP of EnDASH: accounts for vertical handovers or connection to different network technologies.

How EnDASH works?



1. Predict average throughput at time slot $n+1$, $\hat{\tau}(\mathrm{n}+1) = \mathcal{F}(\tau(n))$
2. Predict play-out buffer length at time slot $n+1$, $\hat{b}(\mathrm{n}+1) = \mathcal{F}(\hat{\tau}(\mathrm{n}+1))$
3. Predict Next Chunk Quality as a function of $\hat{b}(\mathrm{n}+1)$

The EnDASH flow



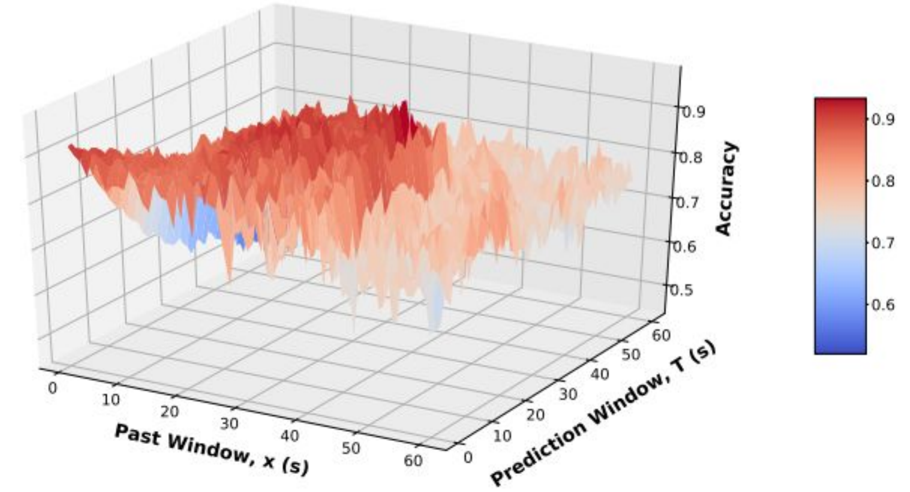
- RSSI – Received Signal Strength Indicator
- Quantifies the signal strength

Throughput Prediction Algorithm

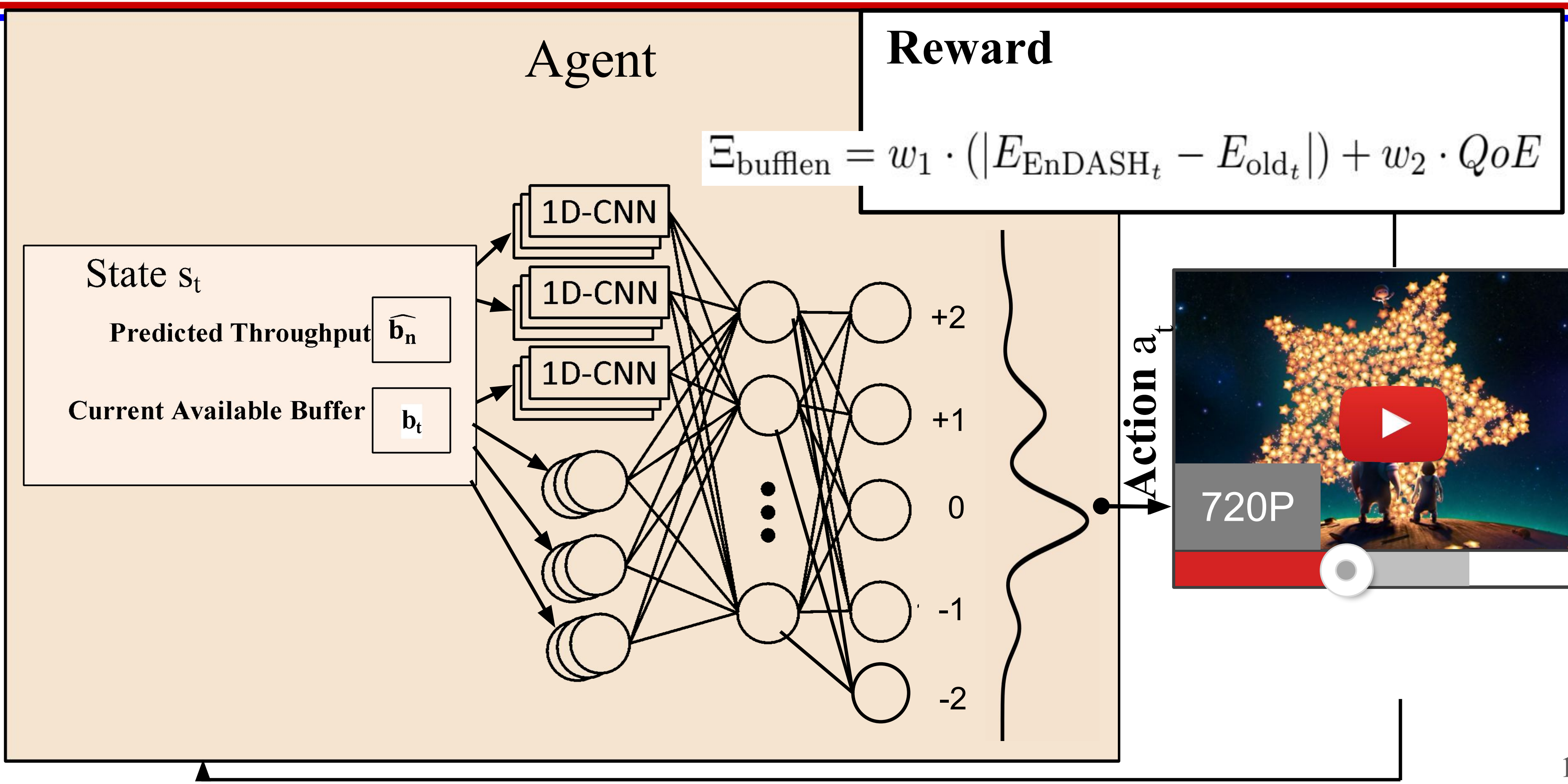
- A supervised learning algorithm - Random Forest Learning
  - Two phases: Training and Test
  - Train-Test split: 70-30
- Historical information of previous '*x*' seconds of various radio related parameters used to predict the average throughput experienced by a user in the next T seconds.
  - Represented as $P_x F_T$.
- Data Processing:
  - Each parameter a random quantity;
  - Instead of feeding entire data statistically important metrics fed
  - Derive quantities like Mean, median, 25^{th}, 75^{th}, 90^{th} percentiles
- Random Forest Regressor: 100 Estimators
- Features: RSSI, Network Type, Base Station Id, Number and Type of neighbouring BSs

Throughput Prediction – Results

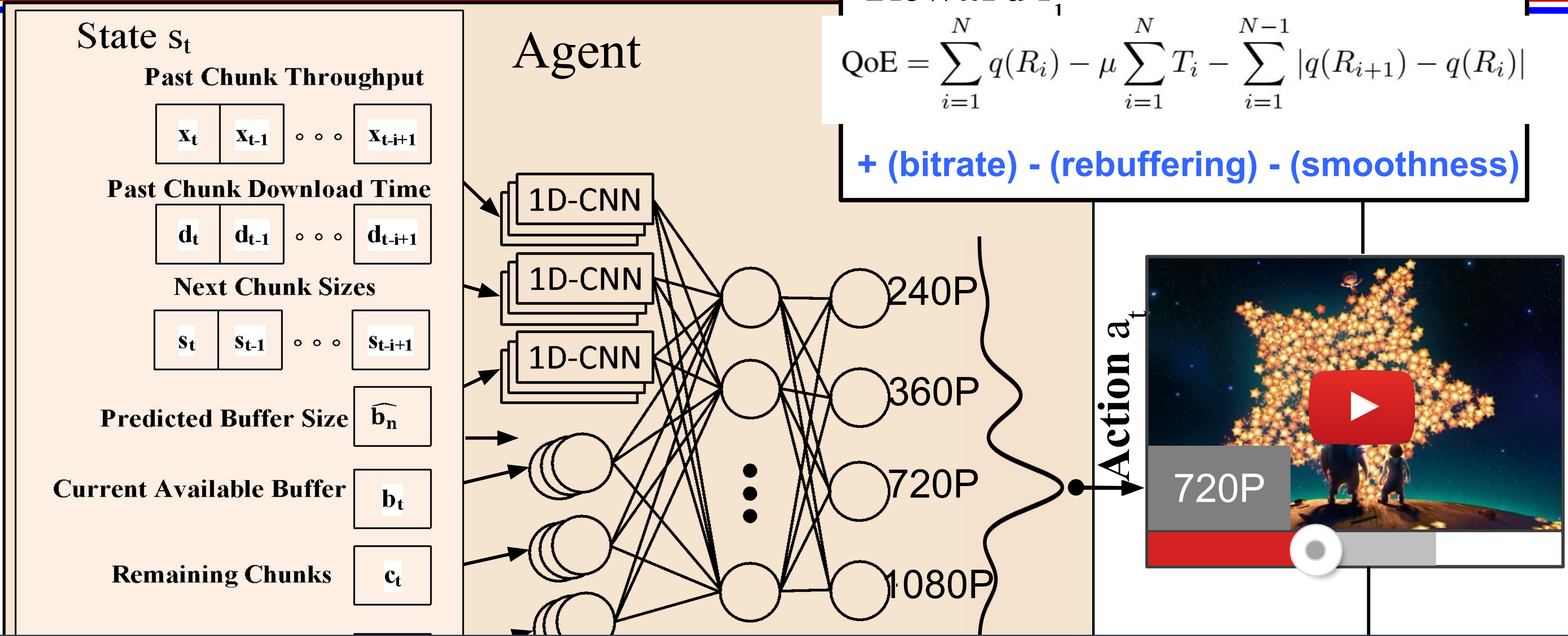
Dataset	Accuracy	Mean cross-validation accuracy	Variance	Feature with maximum feature importance	Value of maximum feature importance
Kharagpur	95.96 % (8780 training samples & 2196 test samples)	0.96	5.39E-05	Past 90th percentile throughput	0.6



Buffer Length Selection RL Model



Bitrate Selection RL Model



Reward r_i

$$QoE = \sum_{i=1}^{N} q(R_i) - \mu \sum_{i=1}^{N} T_i - \sum_{i=1}^{N-1} |q(R_{i+1}) - q(R_i)|$$

+ (bitrate) - (rebuffering) - (smoothness)

We Leverage Pensieve [SIGCOMM'17] for the Bitrate Selection Model

Evaluation Methodology

Trace Driven Evaluation: For Throughput Prediction

- **Dataset:** Dataset consisting of 148 traces on throughput and power consumption
- **Duration:** Trace length varies between 34 seconds to 3298 seconds
- **Formatting:** Formatted to be compatible with MahiMahi Network Emulation Tool

Training the buffer length and bitrate selection models

- **57 DASH-ified videos used, with a total duration of 45 hours**

Throughput Prediction

- **Historical Window Size – 30 seconds**
- **Future Window Size – 30 seconds**

How Does EnDASH Perform?

Evaluation Methodology

- **Rate-based:** pick bitrate based on predicted throughput
  FESTIVE [CoNEXT'12], **PANDA** [JSAC'14], **CS2P** [SIGCOMM'16]

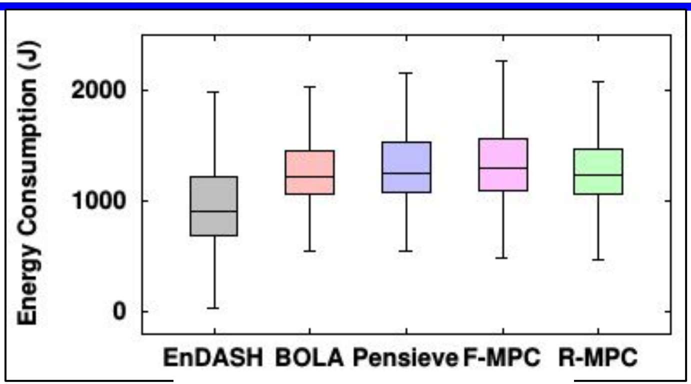
- **Buffer-based:** pick bitrate based on buffer occupancy
  BBA [SIGCOMM'14], **BOLA** [INFOCOM'16]

- **Hybrid:** use both throughput prediction & buffer occupancy
  PBA [HotMobile'15]

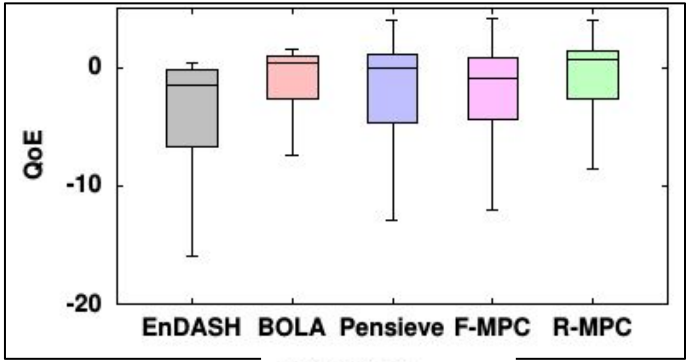
- **QoE-metric based:** optimization problem to maximize QoE metric
  MPC [SIGCOMM'15], **Pensieve** [SIGCOMM'17]

The Baseline Algorithms used in the work highlighted.

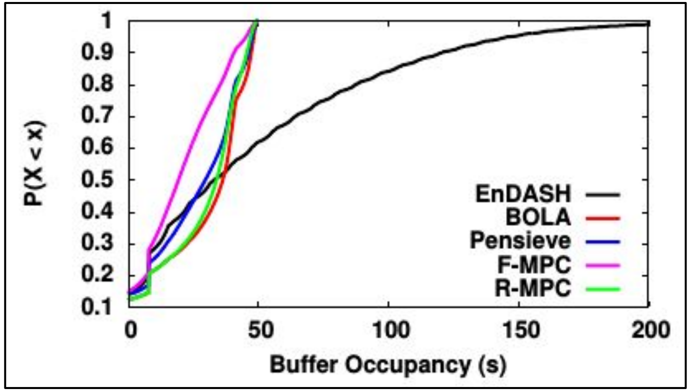
Energy Consumption and QoE



(a) Energy Consumption



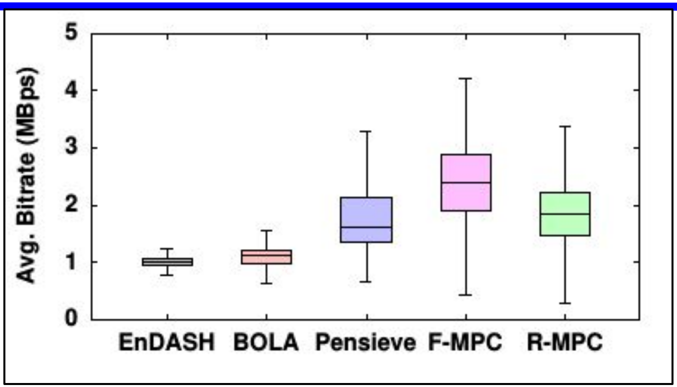
(b) QoE score



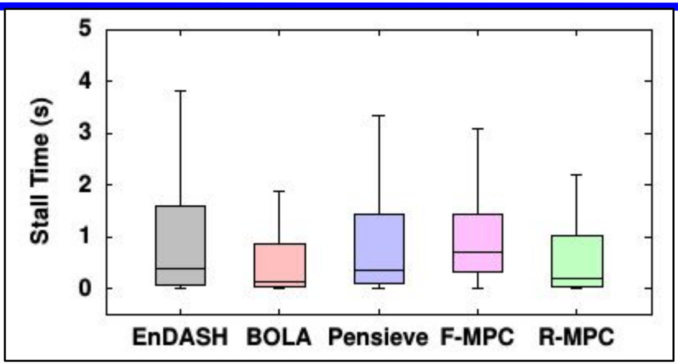
(c) CDF of buffer length of different algorithms

Fig: Performance comparison of EnDASH with baseline ABR streaming algorithms, BOLA [11], Pensieve [10], Fast MPC [13], Robust MPC [13]

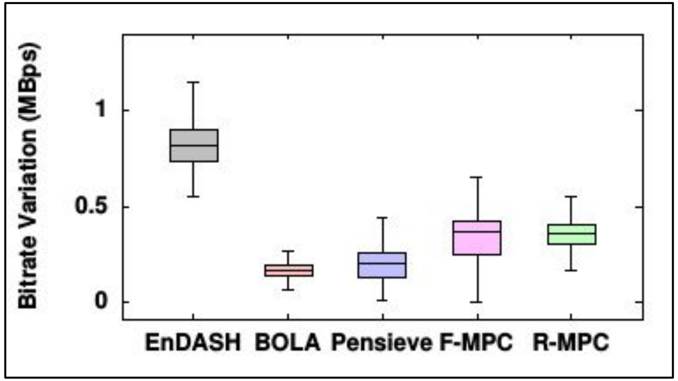
Individual QoE components



(a) Avg. Bitrates in Kbps



(b) Stall Time per segment (in secs)



(c) Bitrate Variation

Fig: Comparison of different components of QoE score (average bitrate, stall time, smoothness) of EnDASH with baseline ABR streaming algorithms, BOLA [11], Pensieve [10], Fast MPC [13], Robust MPC [13]

Results

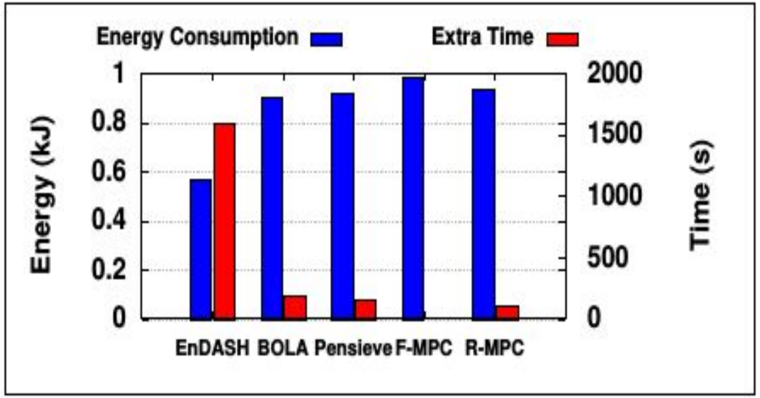
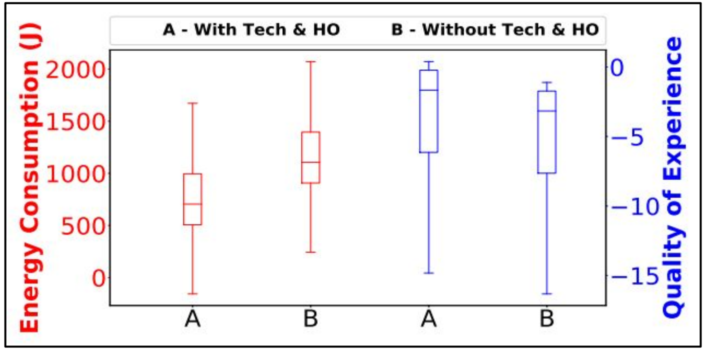


Fig. Energy Consumption and Extra Playtime obtained w.r.t. Fast MPC, which has the highest energy consumption

Fig: Impact of considering associated technology and vertical handovers (HOs) on EnDASH; for $P_{30}F_{30}$



Look-Ahead

- What we have:
  - An energy efficient mobility adapted video streaming algorithm - EnDASH
  - Saves energy with some compromise in QoE and also in memory usage in terms of increased buffer length.
  - Offers nearly 29% increase in video viewing time
- Look Ahead
  - Work in progress for app development
  - Implementation of EnDASH for base-station assisted energy management in smartphones

Thank you

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Impact of features on throughput prediction

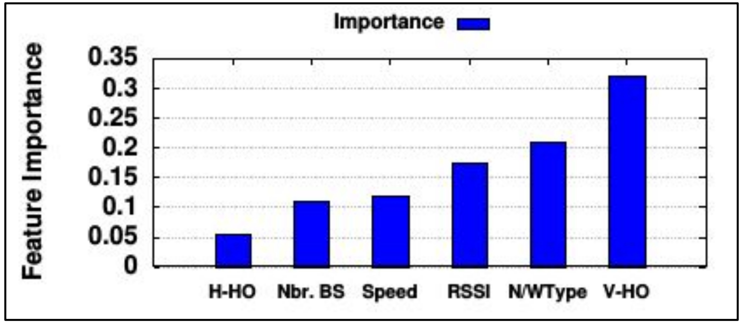

Fig: Feature Importance

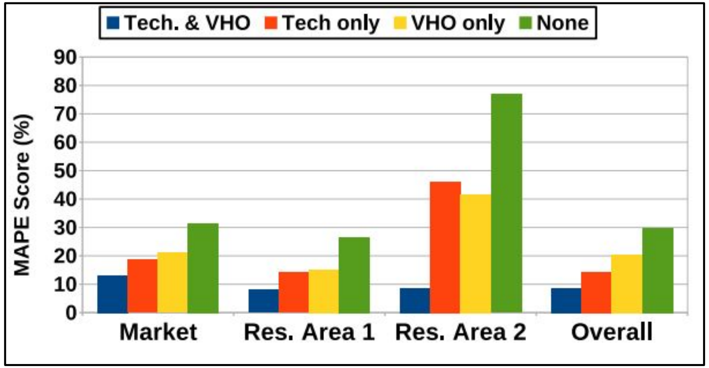

Fig: MAPE score measuring error of thpt prediction in different regions for P30F30

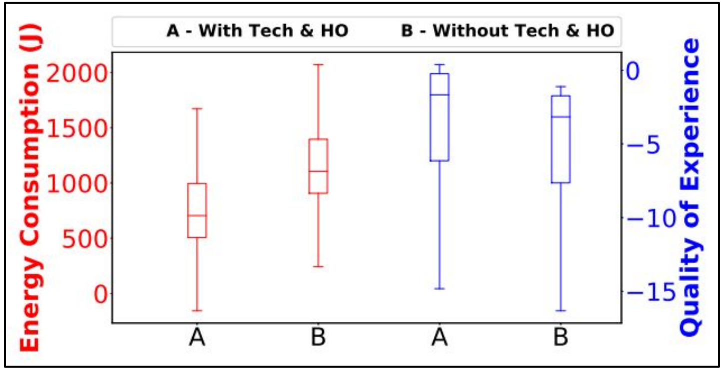

Fig: Impact of considering associated technology and vertical handovers (HOs) on performance metrics of EnDASH; for P30F30