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Challenges for a data-driven society

Machine Learning Approach for Quality Adaptation of Streaming Video Through 4G Wireless Network over HTTP

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Outline

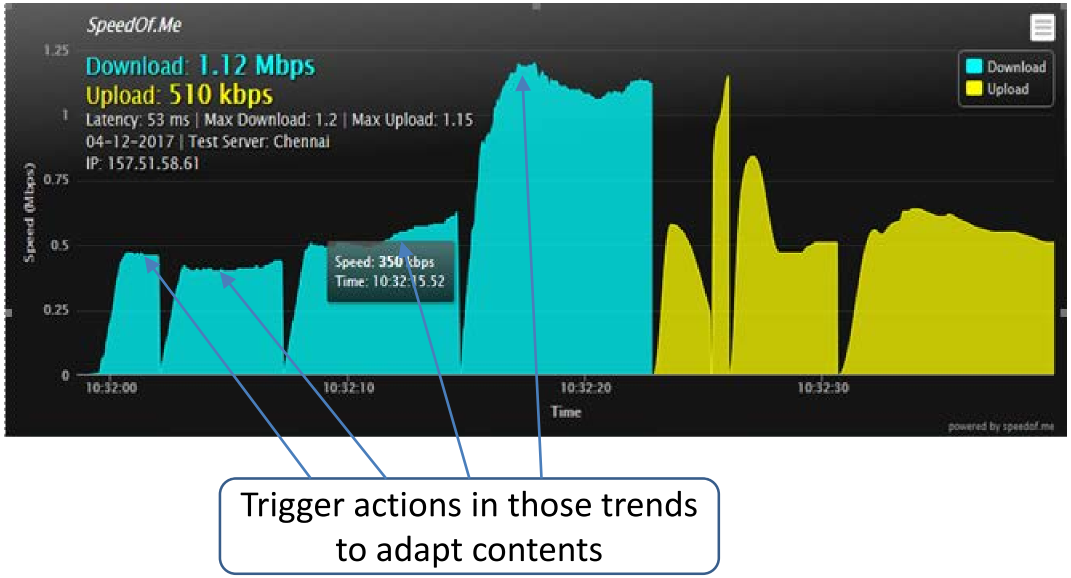
- Motivation
- System Model and Development
- Machine Learning Approach
- Algorithm Development
- Experimental Results
- Conclusion

Motivation

- **Bit Rate Fluctuation in Internet over 4G Wireless**
  - Internet service based on Best-effort model
  - Received signal strength fluctuation in wireless channel

Solutions?

- ➢ Change in underlying hardware and network
- ➢ Migration to 5G
- ➢ Content adaptation on-the-top of HTTP



System Model

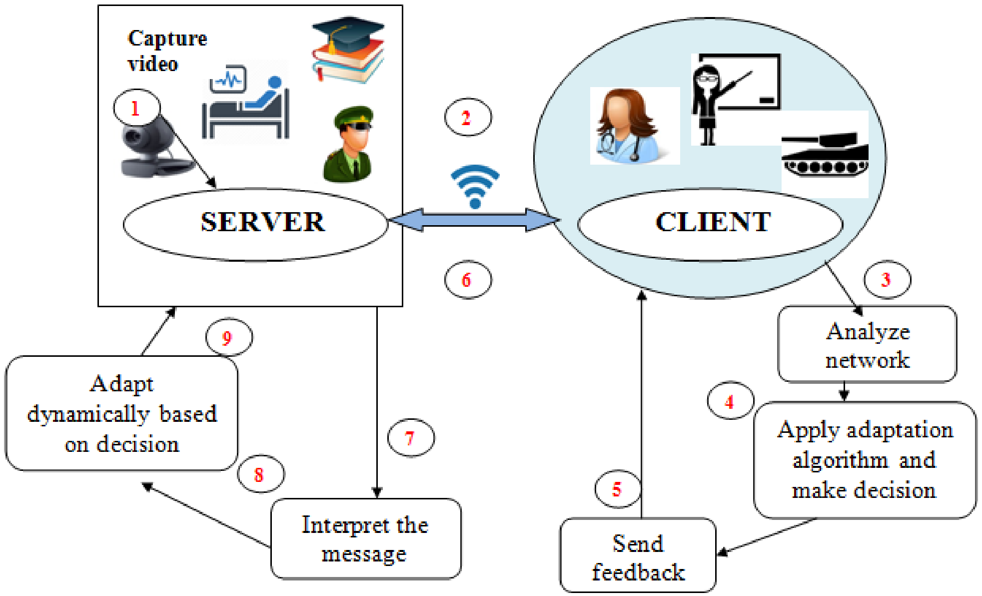


Fig.1. The Client Server Model

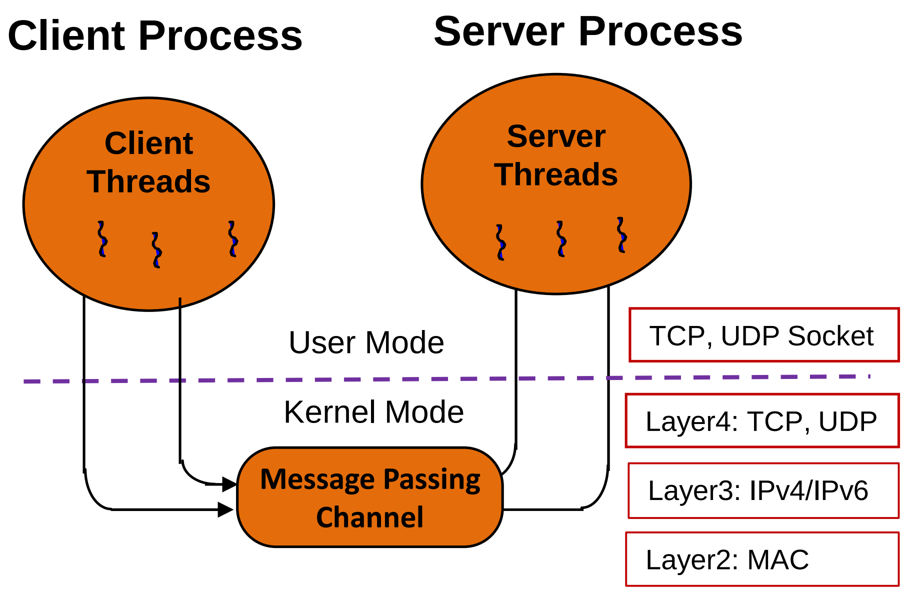


Fig.2. Multi-threaded Client-Server Communication

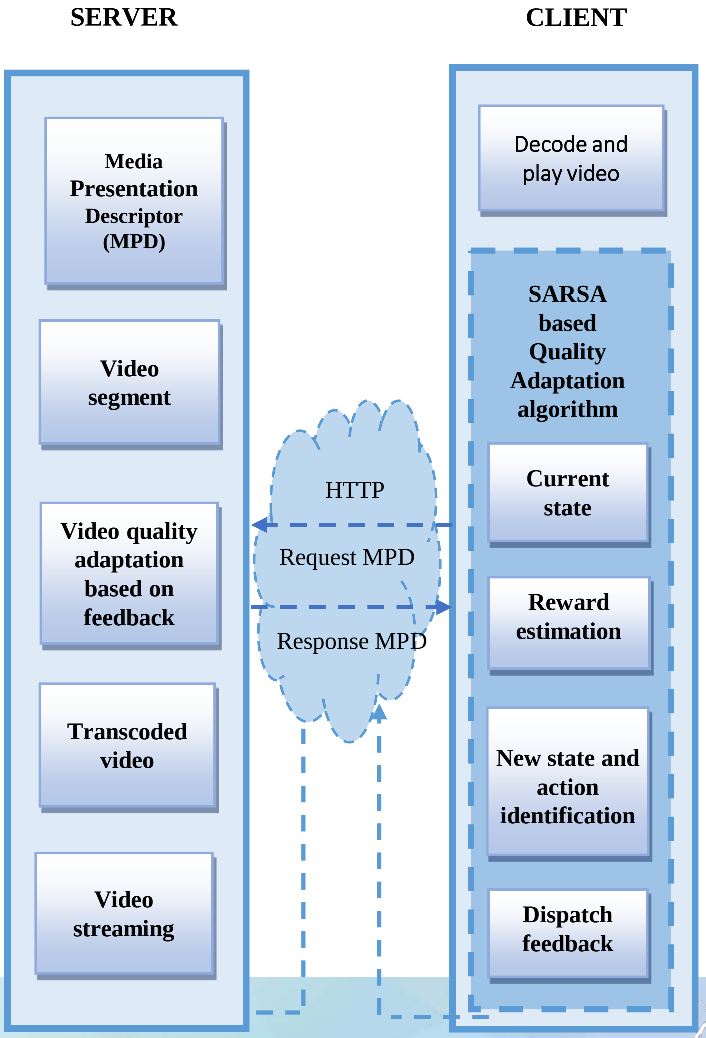
System Development

Adaptive Streaming System

- ➢ Media Capture
- ➢ Adaptation Procedure
- ➢ Content Encoding / Transcoding
- ➢ Stream Processing

Content Transcoding at Server

- ❖ Quality estimation through standard procedures (**ITU-T G.1070**) at client
- ❖ Trigger action based on machine learning (**State Action Reward State Action (SARSA)**) at client



State Action Reward State Action (SARSA) Approach

The Q-matrix is updated after each quality decision as follows.

$$Q[s_{cur}, a_{cur}] \leftarrow Q[s_{cur}, a_{cur}] + \alpha \left[V_q + \gamma\, Q(s_{new}, a_{new}) - Q(s_{cur}, a_{cur}) \right] \quad (1)$$

where $\boldsymbol{\alpha}$ denotes *learning rate*, γ *discount factor*, and $\boldsymbol{v_q}$ associated immediate *reward*

SARSA Base Quality Adaptation (SBQA):

(1) **Softmax Policy**: The action is chosen according to the resulting distribution, which is the Boltzmann distribution given by

$$P(a_j) = \frac{e^{-\frac{Q(s,a_j)}{r}}}{\sum_{i=1}^{|a_S|} e^{-\frac{Q(s,a_i)}{r}}} \quad (2)$$

(2) **ε-greedy Policy**: the agent selects at each time step a random action with a fixed probability, 0 <ε<1

$$Action = \begin{cases} random\_action\_from\_A(s)\,, & if\ r < \varepsilon \\ argmax_{a\ \varepsilon\ A(s)} Q(s,a), & otherwise \end{cases} \quad (3)$$

ITU-T G.1070 Based Video Quality Evaluation

The video quality (V_q) is represented as

$$V_q = 1 + I_c I_t \quad (4)$$

Where I_c represents the basic video quality resulting from the encoding distortion, I_t is the factor governed by degree of robustness due to packet loss.

I_c is expressed in terms of bit rate (b) and frame rate (f) according to equations (5 - 8) as follows.

$$I_c = I_0 \, e^{-\frac{(\ln(f)-\ln(f_0))^2}{2D_{Fr}^2}} \quad (5)$$

$$f_0 = v_1 + v_2 \, b \quad (6)$$

$$D_{Fr} = v_6 + v_7 \, b \quad (7)$$

$$I_0 = v_3 \left(1 - \frac{1}{1+\left(\frac{b}{v_4}\right)^{v_5}}\right) \quad (8)$$

I_t depends on packet loss robustness factor ($D_{P_{plv}}$) and rate of packet loss (p) given by

$$I_t = e^{-\frac{p}{D_{P_{plv}}}} \quad (9)$$

$$D_{P_{plv}} = v_{10} + v_{11} e^{-\frac{f}{v_8}} + v_{12} e^{-\frac{b}{v_9}} \quad (10)$$

SBQA Using Softmax Policy (SBQA-SP) Algorithm

1. Initialize with number of packets ***N***, learning rate $\boldsymbol{\alpha}$ and discount factor $\boldsymbol{\gamma}$, last state $\boldsymbol{s_{last}}$ and Q-matrix $\boldsymbol{Q}$.
2. Compute throughput (***Th***) resulting from the capture of ***N*** packets.
3. Identify current state $\boldsymbol{s_{cur}}$ based on ***Th*** value.
4. Read the resolution ***res***, and frame per second ***fps*** from the header in streamed video.
5. Determine current action $\boldsymbol{a_{cur}}$ based on the current quality segment.
6. While $s_{cur} < s_{last}$ *// till last state reached*
7. Read the encoded bit rate ***b***, and compute frame loss percentage ***p***.
8. Calculate the reward (video quality) $\boldsymbol{V_q}$ using (4)
9. Estimate the current throughput $\boldsymbol{Th_{cur}}$ and based on $\boldsymbol{Th_{cur}}$ identify new state $\boldsymbol{s_{new}}$.
10. Compute new action $a_{new} \leftarrow$ SoftMax(Q,s).
    // Exploration policy function to get best possible future action
11. Update the $Q[s_{cur}, a_{cur}]$ based on (1)
12. $s_{cur} \leftarrow s_{new}$ // Update new state to the current state
13. $a_{cur} \leftarrow a_{new}$ // Update new action to the current action
14. Assign action $\boldsymbol{a_{cur}}$ as feedback to the server
15. End
16. Go to Step 2 and continue till streaming occurs
17. End

SBQA Using ε-Greedy Policy (SBQA-GP) Algorithm

1. Initialize fixed probability ε and *max* // *Store maximum value (max) in* s^{th} *row of Q-matrix.*
2. Generate a random value *ran* in the range 0 to 1.
3. If *ran* < ε
4. *selectedAction* = -1
5. Else
6. For *i* = 1 to Q_{length} // *get* Q_{length} *from Q-matrix*
7. If *Q[s,i]* >= *max*
8. *selectedAction* = *i* // *action with max reward*
9. *max* = *Q[s,i]*
10. End
11. If *selectedAction* = -1
12. Generate a random number *r*, in range of action.
13. *selectedAction* = *r*
14. Return *selectedAction*

Q-Learning Based Quality Adaptation (QBQA) Algorithm

1. Initialize the learning rate $\boldsymbol{\alpha}$, discount factor $\boldsymbol{\gamma}$, Q-matrix, and optimal bandwidth value $\boldsymbol{B_{opt}}$.
2. Read the current buffer occupancy level $\boldsymbol{buf_k}$ for k^{th} segment and quality level q_{k-1} for segment k-1
3. For i = 1 to t *// Training Phase*
4. Estimate the bandwidth $\boldsymbol{bw_k}$
5. Assign $s_k = \{ bw_k, buf_k, q_{k-1} \}$ *// Current State*
6. a_k = Softmax(Q, s_k) *// Exploration policy function to get best possible action.*
7. Calculate the quality factor related to bandwidth and buffer occupancy level using the equation

$$R_{quality} = -1.5 \, . \left| bw_k . \frac{1+(buf_k/B_{opt})}{3-(bw_1/a_1)} - a_k \right|$$

8. Calculate the quality factor related to switch in quality using the equation

$$R_{switches} = -|q_{k-1} - a_k|$$

9. Read the duration of video freeze $\boldsymbol{t_{stall}}$, time elapsed from the last freeze $\boldsymbol{t_{play}}$ and number of freezes $\boldsymbol{n}$
10. Calculate the quality factor related to video freezing using the equation

$$R_{freezes} = \begin{cases} -100 \, . \left| \frac{a_k}{bw_k} \, . \, \frac{e^{\frac{t_{stall}}{10}}}{\ln(t_{play}+1)} \right| & a_k = a_1 \\ -100 \, . \left| \frac{a_k}{bw_k} \, . \, \frac{e^{n+\frac{t_{stall}}{10}}}{\ln(t_{play}+1)} \right| & a_k \neq a_1 \end{cases}$$

11. Calculate

$$R_{total} = R_{quality} + R_{switches} + R_{freezes}$$

12. End
13. Determine the resultant state, s_{k+1} using$\{ bw_{k+1}, buf_{k+1}, q_k \}$
14. Update the Q-matrix using

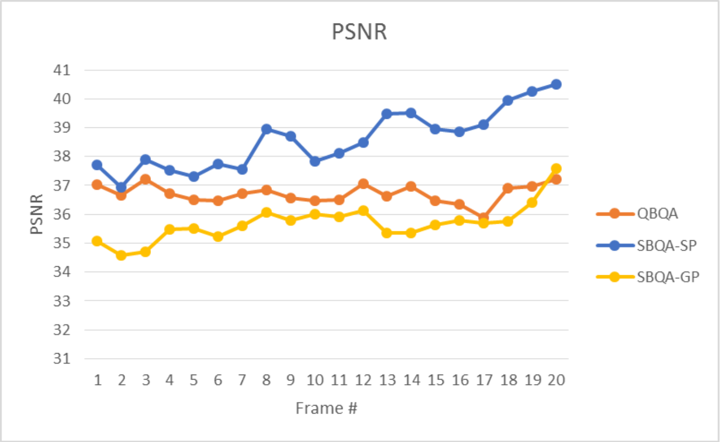
$$Q[s_k, a_k] \leftarrow (1-\alpha)\, Q[s_k, a_k] + \alpha[\, R_{total} + \gamma \, max_b Q(s_{k+1}, b)]$$

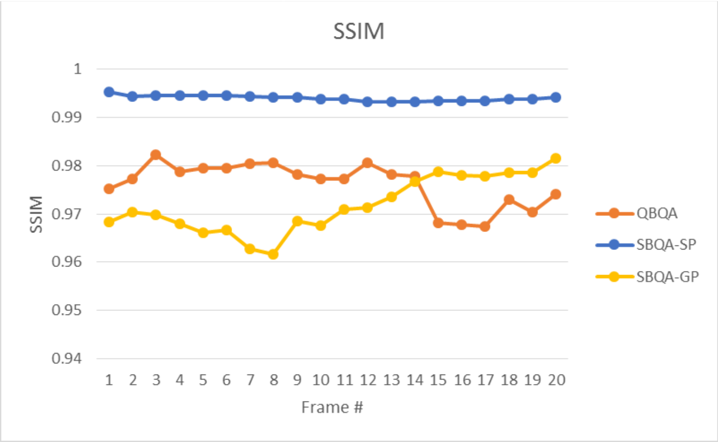
15. Estimate the bandwidth $\boldsymbol{bw_k}$ *// Testing Phase begins*
16. Assign $s_k = \{ bw_k, buf_k, q_{k-1} \}$
17. a_k = max$_a$ (Q(s_k, a))
18. Send $\boldsymbol{a_k}$ as feedback to the server
19. Repeat from Step 15 until streaming occurs

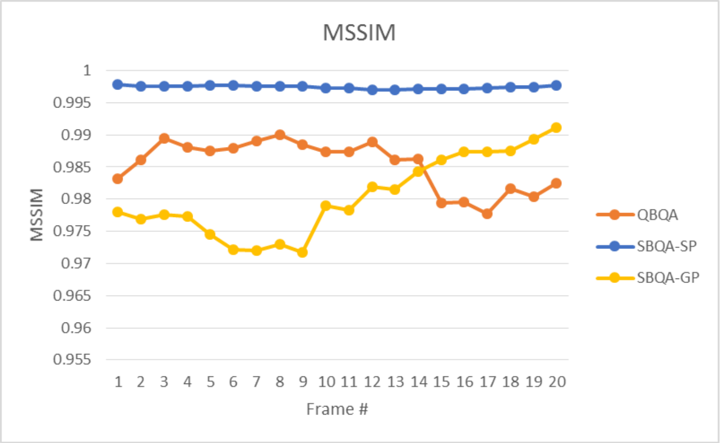
Experimental Results

Test Parameters as per ITU-T J.247

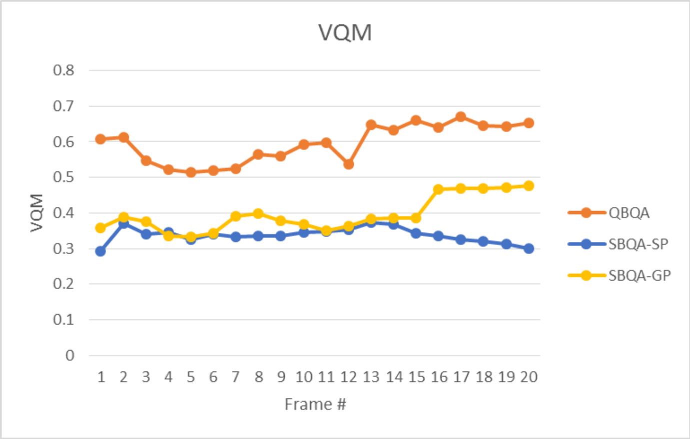
S.no	Parameters	Values
1.	Transmission	Errors with packet loss
2.	Frame Rate	5 fps to 30 fps
3.	Video Codec	H.264/AVC (MPEG-4 part10), VC-1, Windows Media9, Real Video (RV 10), MPEG-4 Part 2
4.	Video Resolutions and bit rates	QCIF: 16 - 320 kbps CIF: 64 - 2000 kbps VGA: 128 - 4000 kbps
5.	Temporal errors (pausing with skipping)	Maximum of 2 seconds

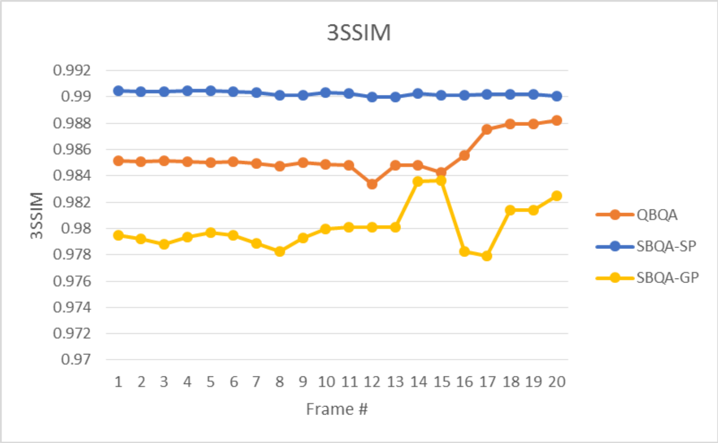


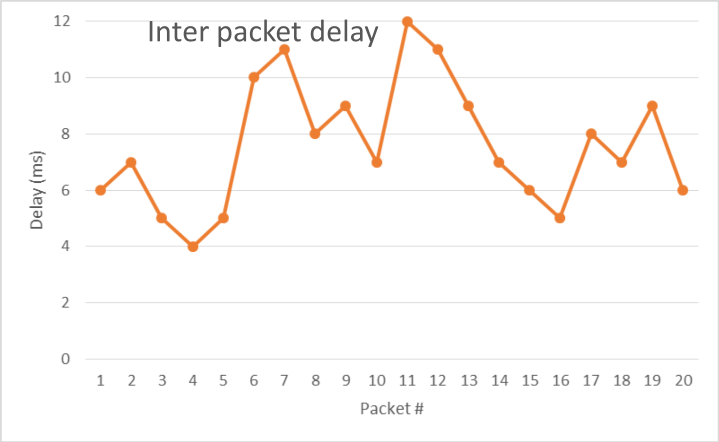




Experimental Results cont.







Experimental Results cont.

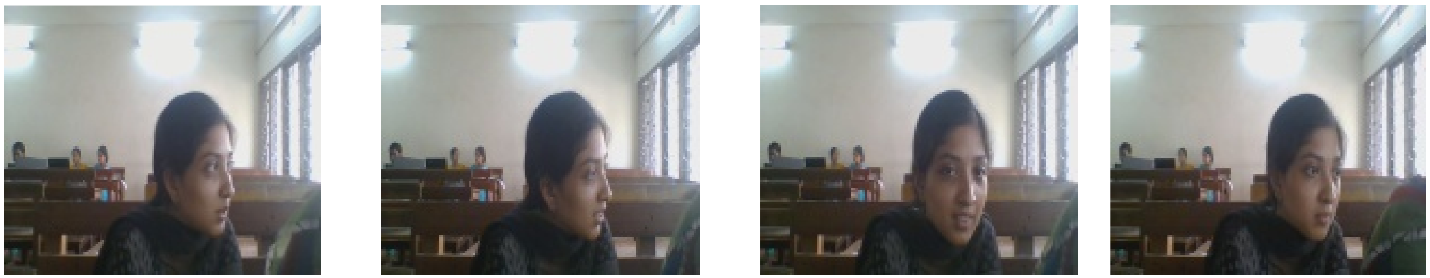


Fig.(a) Original Live Video

Fig.(b) Decoded at Receiver

Conclusions

- On-the-top (OTT) implementation with the last mile connectivity through 4G mobile
- ITU-T G.1070 model embedded in the algorithm
- The State Action Reward State Action (SARSA) approach achieves the system goal
- Experiments conducted on live / stored video stream and results validated through FR metrics
  - PSNR, SSIM, MS-SSIM, VQM, and 3-SSIM
- Implementation of multi-casting service will require additional mechanism

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