SVC Video Transmission through Multi-RAT Network

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Bio

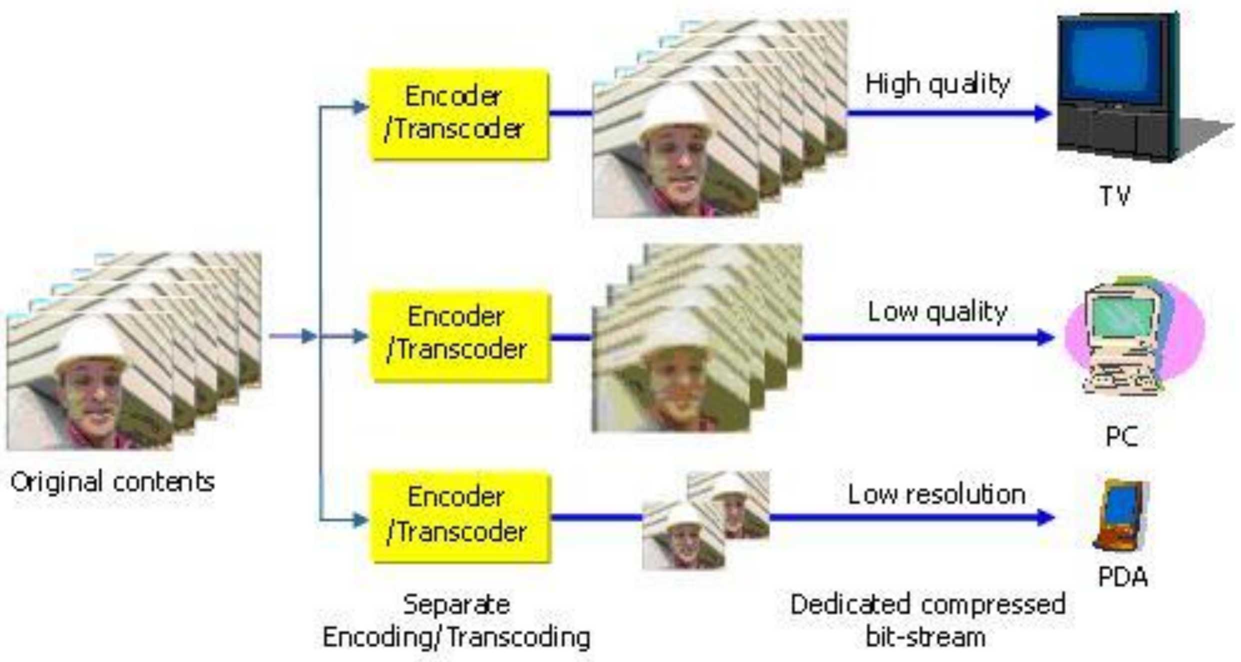
- Dr. Jounsup Park joined as an Assistant Professor in the Department of Electrical Engineering at UT Tyler in Fall 2020. He completed his postdoctoral training in Coordinated Science Lab at the University of Illinois at Urbana-Champaign, Illinois in 2020. Dr. Park received his Ph.D. in Electrical Engineering from the University of Washington, Seattle, Washington in 2018. He received his B.Sc. and M.Sc. in Electrical Engineering from Korea University, Seoul, Korea, in 2006 and 2008, respectively.

Outline

- Introduction
  - Scalable Video Coding
  - Quality of Experience
  - Multi-RAT
- System model
- Problem formulation
- Problem solving strategy
- Simulation results
- Conclusion

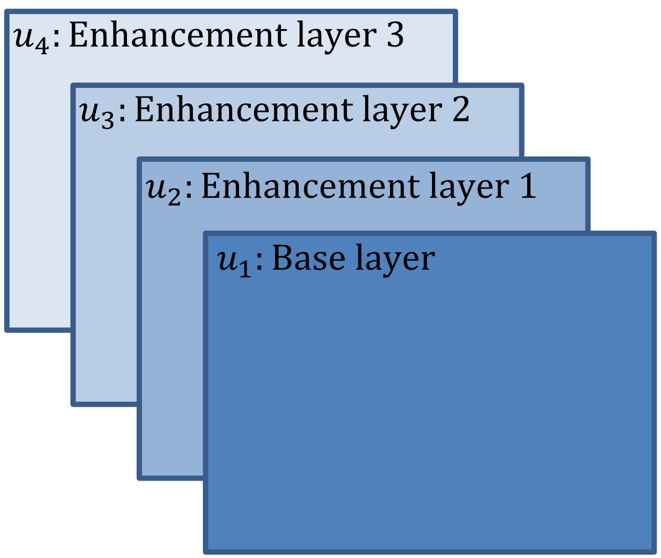
Scalable Video Coding (SVC)

- Some portions of the video bit-streams can be discarded and can still be decoded
- Can adjust bit-rate depending on the channel condition
- Control the quality of the video



Quality of Experience (QoE)

- How can QoE be measured?
- Full reference : need original video data
  - Peak Signal-to-Noise Ratio (PSNR)
  - Structural SIMilarity (SSIM)
- Non-reference
  - Quality measure by using SVC concept
  - Quantify the QoE of each layer



$$\sum_{l=1}^{L} u_l = 1,$$

$$\text{where } u_l = \begin{cases} e^{c\left(1-\frac{q_l}{q_{min}}\right)}, & l = 1, \\ e^{c\left(1-\frac{q_l}{q_{min}}\right)} - e^{c\left(1-\frac{q_{l-1}}{q_{min}}\right)}, & l \geq 2, \end{cases}$$

c : video dependent model parameter
q_l : quantization step-size
q_{min} : minimum quantization step-size

Multi-RAT

- Small cell wireless network architecture is useful to get better coverage the higher throughput

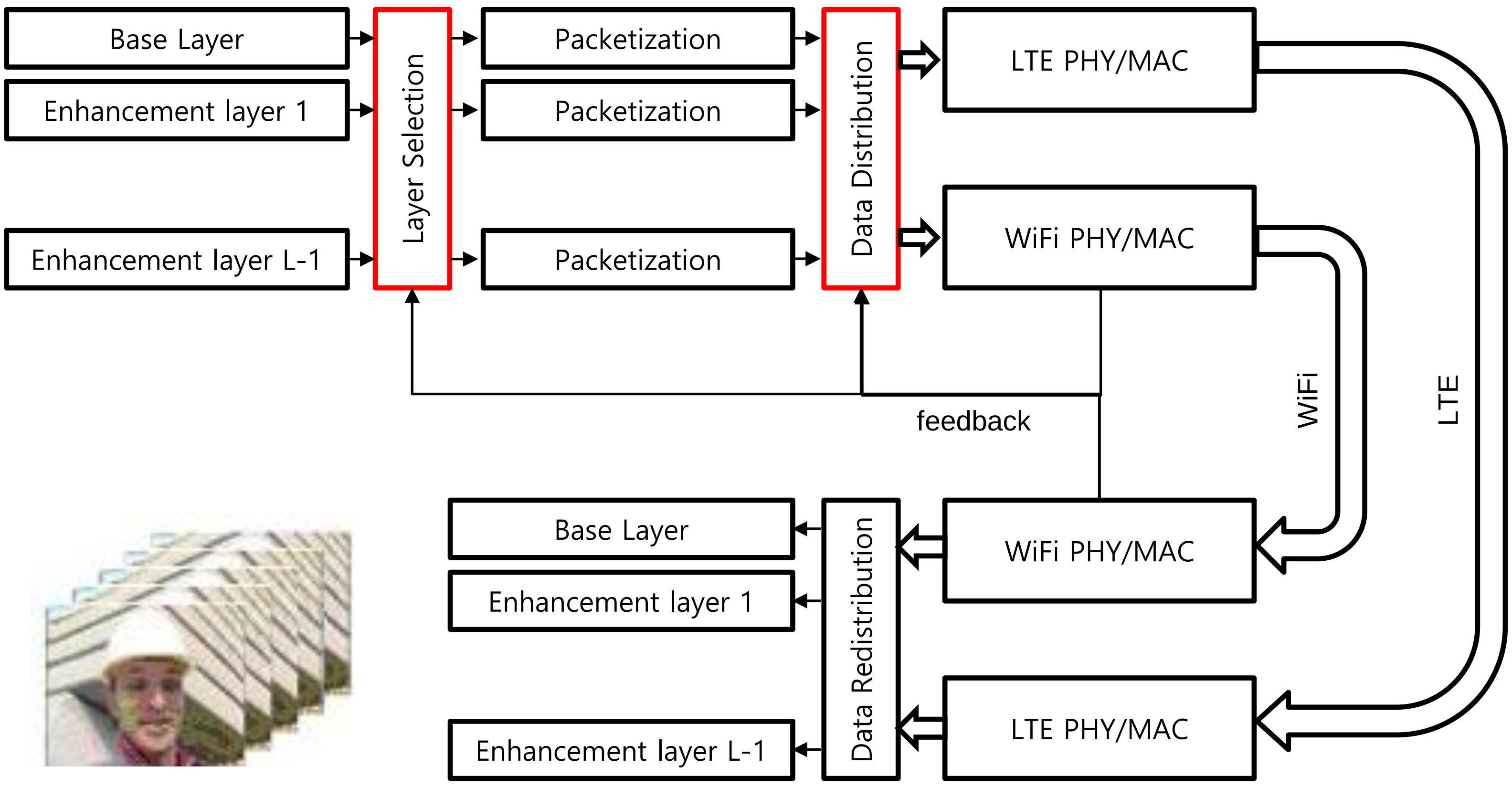
- Multi-RAT is one of the most practical solution for small cell deployment

- Multiple Radio Access Technology (Multi-RAT)
  - Utilizing multiple radio access technologies at the same time to achieve better throughput or user experience
  - Today’s mobile devices are mostly equipped with 3G and Wi-Fi

- In this project, only the LTE and the Wi-Fi are considered

System Model

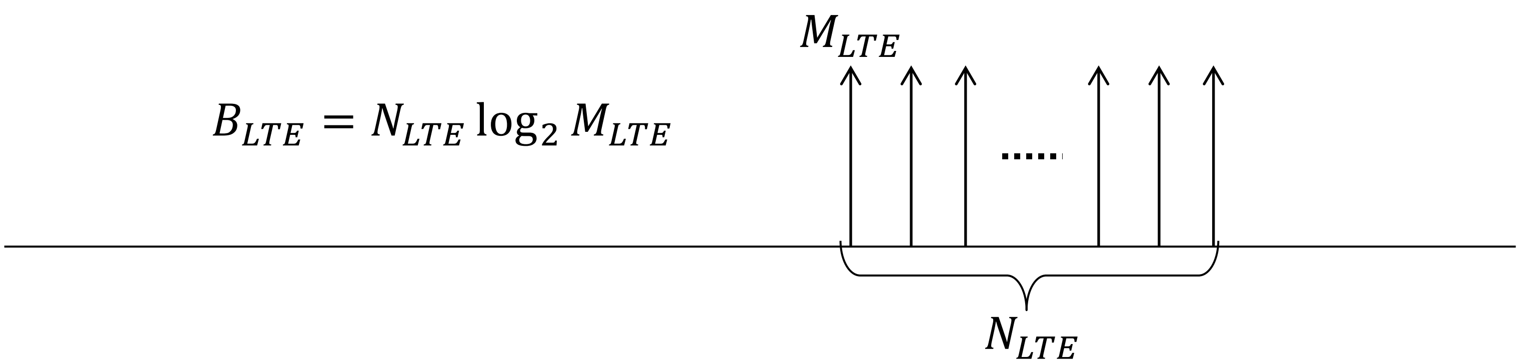
- Utilize the PHY/MAC information to find the optimal rate distribution



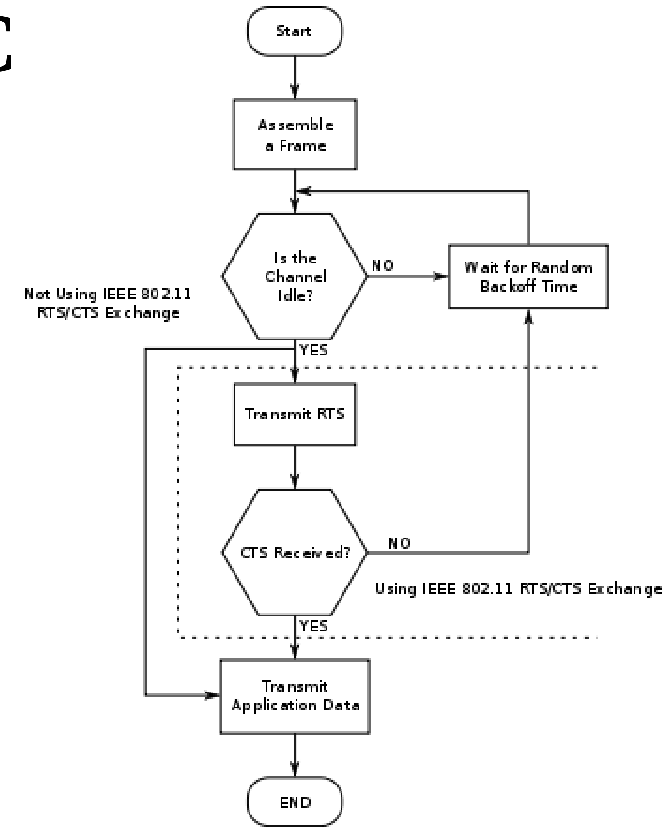
LTE PHY/MAC

- PHY
  - OFDM : 128, 256, 512, 1024, 1536, 2048
  - Modulation : BPSK, QPSK, 16-QAM, 64-QAM
- MAC
  - OFDMA
  - Can utilize the part of subcarriers
- Data rate : $\frac{B_{LTE}}{T}$
  - k_{LTE} OFDM symbols per packet
  - OFDM symbol duration T

$$B_{LTE} = N_{LTE} \log_2 M_{LTE}$$

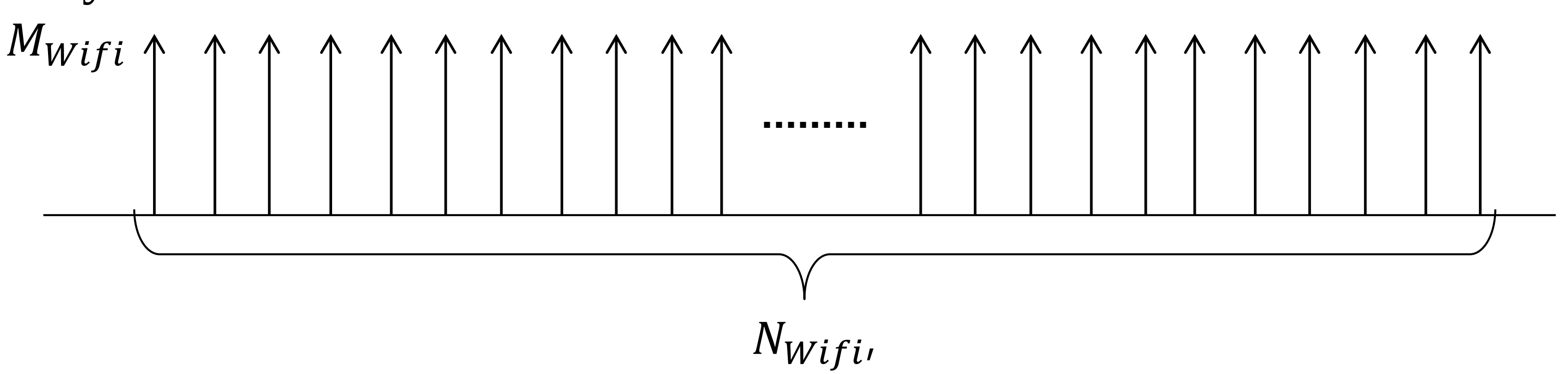


WiFi PHY/MAC



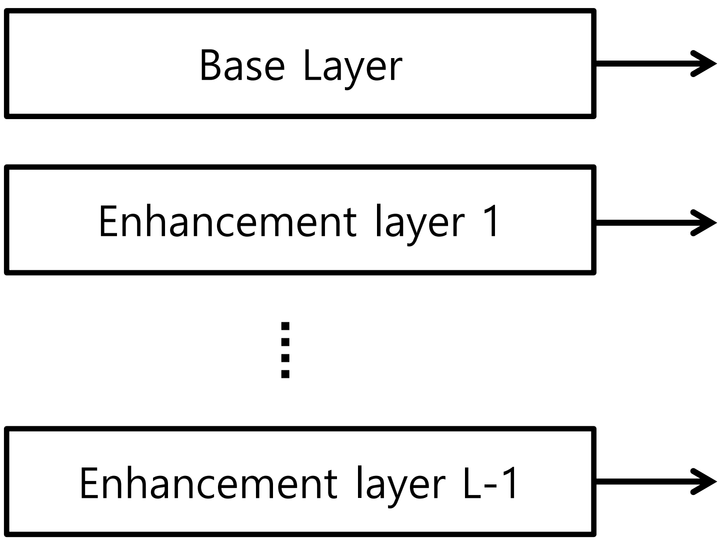
- PHY
  - OFDM : 64, 128, 256, 512
  - Modulation : BPSK, QPSK, 16-QAM, 64-QAM
- MAC
  - DCF(CSMA/CA, RTS/CTS)
- Data rate : $\frac{(k_{wifi}-k_{ov})B_{Wifi}}{k_{wifi}T}$
  - k_{wifi} OFDM symbols per packet
  - Consider the overhead (k_{ov}) to avoid collision
  - Symbol duration T

$$B_{Wifi} = N_{Wifi} \log_2 M_{Wifi}$$



SVC Encoded Video Layers

- One base layer and L-1 enhancement layers
- Each video layer has corresponding datarate, and they will distributed to the LTE and Wi-Fi



$$r_0 \leq r_{0,LTE} + r_{0,Wifi}$$

$$r_1 \leq r_{1,LTE} + r_{1,Wifi}$$

$$r_{L-1} \leq r_{L-1,LTE} + r_{L-1,Wifi}$$

Problem Formulation

- Maximize the utility

$$\max_{\boldsymbol{r}_{LTE},\boldsymbol{r}_{Wifi}} U(r_{LTE}, r_{WiFi}) = \sum_{l=0}^{L-1} u_l f_l(\boldsymbol{r}_{LTE}, \boldsymbol{r}_{Wifi})$$

$$subject\ to \sum_{l=0}^{L-1} r_{l,Wifi} \leq \left(k_{Wifi} - k_{ov}\right)\frac{B_{Wifi}}{k_{Wifi}T}, \sum_{l=0}^{L-1} r_{l,LTE} \leq \frac{B_{LTE}}{T},$$

$$r_l \leq r_{l,LTE} + r_{l,Wifi}, for\ l = 0, 1, \dots, L-1$$

- Correction rate

$$f_l(r_{LTE}, r_{WiFi}) = \prod_{k=0}^{l} \left(1 - P_e(\gamma_{LTE}, M_{LTE})\right)^{ceil\left(\frac{r_{k,LTE}T}{\log_2 M_{LTE}}\right)} \left(1 - P_e\left(\gamma_{Wifi}, M_{Wifi}\right)\right)^{ceil\left(\frac{r_{k,Wifi}T}{\log_2 M_{Wifi}}\right)}$$

where

u_l = utility of l^{th} layer
T = OFDM symbol duration
$\gamma_{LTE/Wifi}$ = received SNR of LTE and Wifi
$M_{LTE/Wifi}$ = Modultion size of LTE and Wifi

Problem Solving

- Take the logarithm to correction rate

$$\overline{f_l}\left(N_{LTE}^k, N_{Wifi}^k\right) = \log f_l\left(r_{LTE}, r_{Wifi}\right)$$
$$= \sum_{k=0}^{l} \alpha_{LTE} N_{LTE}^k + \alpha_{Wifi} N_{Wifi}^k$$

where,

$$N_{LTE}^k = ceil\left(\frac{r_{k,LTE}T}{\log_2 M_{LTE}}\right),$$
$$N_{Wifi}^k = ceil\left(\frac{r_{k,Wifi}T}{\log_2 M_{Wifi}}\right),$$
$$\alpha_{LTE} = \log\left(1 - P_e(\gamma_{LTE}, M_{LTE})\right),$$
$$\alpha_{Wifi} = \log\left(1 - P_e\left(\gamma_{Wifi}, M_{Wifi}\right)\right).$$

Problem Solving

- New problem statement

$$\max_{\boldsymbol{N}_{LTE},\boldsymbol{N}_{Wifi}} \overline{U}(N_{LTE}, N_{WiFi}) = \sum_{l=0}^{L-1} u_l \overline{f_l}\ (\boldsymbol{N}_{LTE}, \boldsymbol{N}_{Wifi})$$

$$subject\ to \sum_{l=0}^{L-1} N_{l,Wifi} \le \frac{k_{Wifi} - k_{ov}}{k_{Wifi}} N_{Wifi},$$

$$\sum_{l=0}^{L-1} N_{l,LTE} \le N_{LTE},$$

$$r_l \le r_{l,LTE} + r_{l,Wifi}, for\ l = 0,1, \dots L-1$$

- N_{LTE}, and N_{Wifi} are integer
- Can convert the problem into the standard Integer Linear Programming problem

Integer Linear Programming

- Standard form

$$\begin{aligned} &\text{maximize}_{\boldsymbol{x}}\ \boldsymbol{f}^T\boldsymbol{x} \\ &\text{subject to } \boldsymbol{Ax} \le \boldsymbol{b}, \\ &\qquad\qquad x \ge 0, \\ &\qquad\qquad \text{and } x \in Z^n \end{aligned}$$

where,

$$\boldsymbol{f}^T = \left[\sum_{\boldsymbol{l=0}}^{\boldsymbol{L-1}} \boldsymbol{\alpha_{l,LTE} u_l} \quad \sum_{\boldsymbol{l=0}}^{\boldsymbol{L-1}} \boldsymbol{\alpha_{l,Wifi} u_l} \quad \dots \quad \boldsymbol{\alpha_{0,LTE} u_0} \quad \boldsymbol{\alpha_{l,Wifi} u_0}\right],$$

$$\boldsymbol{x} = \left[N_{LTE}^0 \quad N_{Wifi}^0 \quad N_{LTE}^1 \quad N_{Wifi}^1 \quad N_{LTE}^2 \quad N_{Wifi}^2 \quad N_{LTE}^3 \quad N_{Wifi}^3\right]^{\boldsymbol{T}}$$

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ -1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -1 & -1 \end{bmatrix}$$

$$\boldsymbol{b} = \left[N_{LTE} \quad N_{Wifi} \quad \frac{-r_0 T}{log2(M)} \quad \frac{-r_1 T}{log2(M)} \quad \frac{-r_2 T}{log2(M)} \quad \frac{-r_3 T}{log2(M)}\right]^T$$

Linear Programming

- Relaxation of the integer linear programming

$$\text{maximize}_{\boldsymbol{x}}\ \boldsymbol{f}^T\boldsymbol{x}$$
$$\text{subject to } \boldsymbol{Ax} \leq \boldsymbol{b},$$
$$x \geq 0.$$

- Rounding the result to find integer result
- Test with city.yuv parameter (N_{LTE} = 30, N_{Wifi} = 120)

α	**LTE (0.9)**	**WiFi (0.9)**
Base	12	49
Layer1	7	26
Layer2	2	9
Layer3	5	18

(a) No overhead

α	**LTE (0.9)**	**WiFi (0.9)**
Base	15	46
Layer1	8	25
Layer2	3	8
Layer3	6	17

(b) K_{ov} = 10

α	**LTE (0.8)**	**WiFi (0.9)**
Base	1	60
Layer1	1	33
Layer2	1	10
Layer3	4	19

(c) K_{ov} = 10

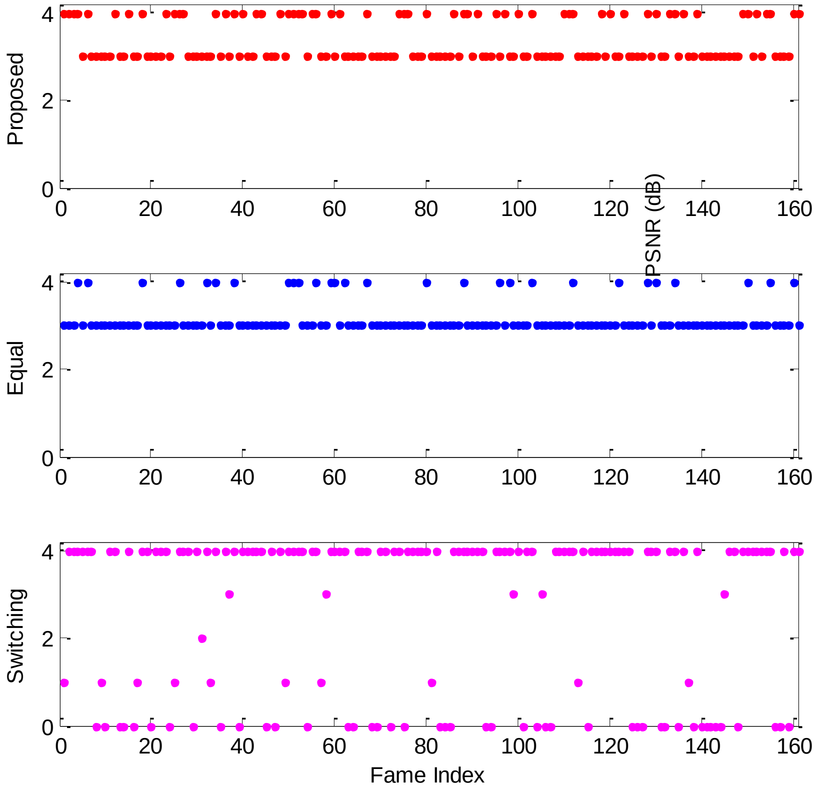
Simulation Settings

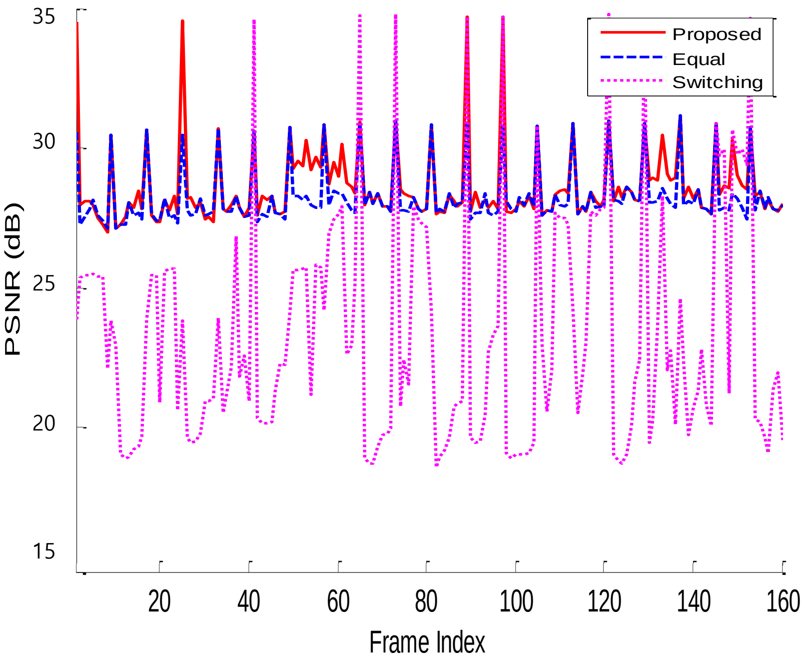
- Tool : Matlab
- Average received SNR : 30dB for two channels (LTE and Wi-Fi)
- Available number of sub-carriers : LTE 60, Wi-Fi 120
- Proposed scheme
  - 4-datastreams are distributed into the LTE and the Wi-Fi with proportions derived from linear programming in the previous page

- Comparison
  - Equal : datastreams are equally distributed into the LTE and Wi-Fi
  - Switching : only one of the channel is used based on received-SNR

Simulation Results

- Fig 1. shows the number of received video layers w.r.t frame index
- Fig 2. shows the PSNR of three different schemes
- Proposed scheme has the best PSNR for all frames





Resulting Videos

Proposed

Equal

Switching

Conclusion

- User can get better quality video by utilizing both the LTE and the Wi-Fi channel at the same time than switching between two channel

- Optimal data distribution solution is found by linear programming

- Optimal solution provide the best QoE to the user