

Report: Joint Scheduling of URLCC and eMBB Traffic in 5G Wireless Networks

Tran Phong Binh

High-Speed Communication and Computing Laboratory, Department of Computer Science, National Tsing Hua University

December 13, 2021

Table of Contents

1 Linear Model

Linear Model

This presentation describes the core idea of [1].

System Model

Without URLLC superposition/puncturing,

$$C_u^{\pi,s} = \mathfrak{c}_u^s \phi_u^{\pi,s}$$

With URLLC superposition/puncturing,

$$\begin{aligned} C_u^{\pi,s} &= \mathfrak{c}_u^s \phi_u^{\pi,s} - \mathfrak{c}_u^s \phi_u^{\pi,s} h \left[\frac{L_u^{\pi,s}}{\phi_u^{\pi,s}} \right] \\ &= \mathfrak{c}_u^s \phi_u^{\pi,s} \left(1 - h \left[\frac{L_u^{\pi,s}}{\phi_u^{\pi,s}} \right] \right) \end{aligned}$$

System Model

With linear URLLC superposition/puncturing,

$$h \left[\frac{L_u^{\pi,s}}{\phi_u^{\pi,s}} \right] = \frac{L_u^{\pi,s}}{\phi_u^{\pi,s}}$$

That is,

$$\begin{aligned} C_u^{\pi,s} &= \mathbf{c}_u^s \phi_u^{\pi,s} \left(1 - \frac{L_u^{\pi,s}}{\phi_u^{\pi,s}} \right) \\ &= \mathbf{c}_u^s (\phi_u^{\pi,s} - L_u^{\pi,s}) \end{aligned}$$

Hence,

$$\mathbb{E} C_u^{\pi,s} = \mathbf{c}_u^s (\phi_u^{\pi,s} - \mathbb{E} L_u^{\pi,s}) \quad (1)$$

System Model

- We assume linear URLLC superposition/puncturing.
- We place URLLC loads uniformly over frequency bandwidth across minislots.
- I assume $\phi_{u,m}^{\pi,s}$ is fixed for a given set of (s, u, m) , for $\mathbb{E}L_{u,m}^{\pi,s}$ in equation 4 to be a proper constant.
- However, I note that such assumption is incorrect because the model aims to modify $\phi_{u,m}^{\pi,s}$ over time.

My Derivation

- Each minislot has an URLLC demand of $\mathbb{E}D_m = \frac{\mathbb{E}D}{m}$.
- Each frequency f in a minislot has an URLLC load of $\mathbb{E}L_{f,m}^\pi$.

$$\begin{aligned}
 \int_0^f \mathbb{E}L_{f,m}^\pi df &= \mathbb{E}D_m \\
 \mathbb{E}L_{f,m}^\pi \int_0^f df &= \frac{\mathbb{E}D}{m} \\
 \mathbb{E}L_{f,m}^\pi f &= \frac{\mathbb{E}D}{m} \\
 \mathbb{E}L_{f,m}^\pi &= \frac{\mathbb{E}D}{fm}
 \end{aligned} \tag{2}$$

My Derivation

- Each frequency f in a minislot has a resource of $\phi_{f,m}$.

$$\begin{aligned}\int_0^f \phi_{f,m} df &= \frac{1}{m} \\ \phi_{f,m} &= \frac{1}{fm}\end{aligned}\tag{3}$$

- By equations 2 and 3,

$$\begin{aligned}\frac{\mathbb{E}L_{f,m}^\pi}{\phi_{f,m}} &= \mathbb{E}D \\ \mathbb{E}L_{f,m}^\pi &= \phi_{f,m}\mathbb{E}D\end{aligned}$$

My Derivation

On the other hand,

$$\begin{aligned} f t &= 1 \\ f t' m &= 1 \\ t' &= \frac{1}{f m} \end{aligned}$$

Furthermore,

$$\begin{aligned} \zeta_{u,m}^{\pi,s} t' &= \phi_{u,m}^{\pi,s} \\ \zeta_{u,m}^{\pi,s} &= \phi_{u,m}^{\pi,s} f m \end{aligned}$$

My Derivation

Thence,

$$\begin{aligned}
 \mathbb{E}L_{u,m}^{\pi,s} &= \int_0^{\zeta_{u,m}^{\pi,s}} \mathbb{E}L_{f,m}^{\pi} df \\
 &= \int_0^{\phi_{u,m}^{\pi,s} \mathfrak{m}} \phi_{f,m} \mathbb{E}D df \\
 &= \mathbb{E}D \int_0^{\phi_{u,m}^{\pi,s} \mathfrak{m}} \phi_{f,m} df \\
 &= \phi_{u,m}^{\pi,s} \mathbb{E}D
 \end{aligned} \tag{4}$$

Similar derivations for slot give

$$\mathbb{E}L_u^{\pi,s} = \phi_u^{\pi,s} \mathbb{E}D \tag{5}$$

Conclusion

By equations 1 and 5,

$$\begin{aligned}\mathbb{E}C_u^{\pi,s} &= \mathfrak{c}_u^s (\phi_u^{\pi,s} - \phi_u^{\pi,s} \mathbb{E}D) \\ &= \mathfrak{c}_u^s \phi_u^{\pi,s} (1 - \mathbb{E}D)\end{aligned}\tag{6}$$

Equation 6 shows that URLLC superposition/puncturing linear model has fixed channel capacity; that is, URLLC scheduling policy can be chosen to be uniform random replacement, and we only have to optimize eMBB scheduling policy.

Reference

- [1] Arjun Anand, Gustavo de Veciana, and Sanjay Shakkottai. “Joint Scheduling of URLLC and eMBB Traffic in 5G Wireless Networks”. In: *IEEE/ACM Transactions on Networking* 28.2 (2020), pp. 477–490. DOI: 10.1109/TNET.2020.2968373.