

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

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## 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  $\mathbb{E}L_{f,m}^\pi$ .

$$\int_0^f \mathbb{E}L_{f,m}^\pi df = \mathbb{E}D_m$$

$$\mathbb{E}L_{f,m}^\pi \int_0^f df = \frac{\mathbb{E}D}{m}$$

$$\mathbb{E}L_{f,m}^\pi f = \frac{\mathbb{E}D}{m}$$

$$\mathbb{E}L_{f,m}^\pi = \frac{\mathbb{E}D}{fm} \quad (2)$$

# 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] Alexander L. Stolyar. “On the Asymptotic Optimality of the Gradient Scheduling Algorithm for Multiuser Throughput Allocation”. In: *Operations Research* 53.1 (2005), pp. 12–25. DOI: <https://doi.org/10.1287/opre.1040.0156>.