

# Multiplexing URLLC Traffic Within eMBB Services in 5G NR: Fair Scheduling

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# System Model

- One base station, downlink transmission, eMBB and URLLC users.
- Saturated eMBB traffic [1]: Each eMBB user has infinite amount of data to be served.

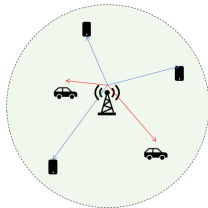


Figure: System model

- $\mu = 2$  for mmWave 28GHz is used ( $\mu \in \{0, 1\}$  is for Sub-6GHz).
- Subchannel bandwidth

$$B_{sc} = 2^\mu \cdot 15 \quad [kHz] \quad (1)$$

$$= 60 \quad [kHz] \quad (2)$$

$$= 6 \cdot 10^4 \quad [Hz] \quad (3)$$

- Time slot duration

$$T_{sl} = \frac{1}{2^\mu} \quad [ms] \quad (4)$$

$$= 0.25 \quad [ms] \quad (5)$$

$$= 2.5 \cdot 10^{-4} \quad [s] \quad (6)$$

# Numerology (Continued)



Figure: Numerology

# System Framework

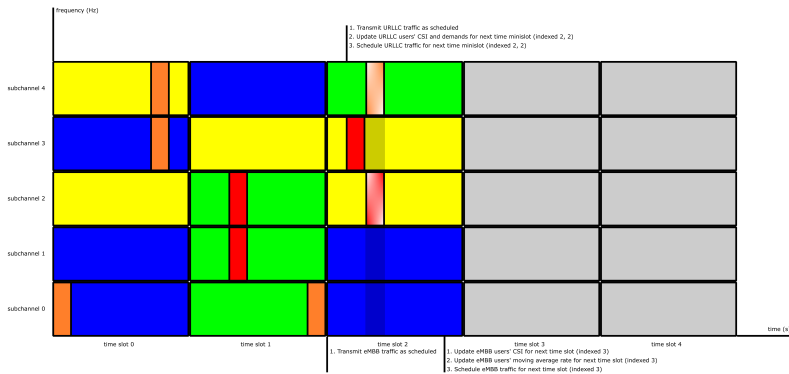


Figure: System framework

# Offline URLLC Puncturing

- The system maximizes eMBB traffic's total average rate and fairness (7a).
- For each time slot, the system allocates at most one eMBB user to each subchannel (7b).
- For each time slot, the system either schedules or un-schedules a subchannel to each eMBB user (7c).
- For each time minislot, the system allocates at most one URLLC user to each subchannel. Also, it schedules  $l^{th}$  subchannel from  $u^{th}$  eMBB user to a URLLC user only if it schedules the subchannel to the eMBB user (7d).
- For each time minislot, the system serves URLLC demands without delay (7e).
- For each time minislot, the system employs URLLC puncturing instead of superposition (7f).

# Offline URLLC Puncturing (Continued)

$$\underset{\alpha, \beta}{\text{maximize}} \quad \sum_u \ln \bar{r}_u \quad (7a)$$

$$\text{subject to} \quad \sum_u \alpha_{u,n,l} \leq 1, \quad \forall n, \forall l, \quad (7b)$$

$$\alpha_{u,n,l} \in \{0, 1\}, \quad \forall u, \forall n, \forall l, \quad (7c)$$

$$\sum_v \beta_{v,u,n,m,l} \leq \alpha_{u,n,l}, \quad \forall u, \forall n, \forall m, \forall l, \quad (7d)$$

$$r_{v,n,m} \geq R_{v,n,m}, \quad \forall v, \forall n, \forall m, \quad (7e)$$

$$\beta_{v,u,n,m,l} \in \{0, 1\}, \quad \forall v, \forall u, \forall n, \forall m, \forall l \quad (7f)$$

# Offline URLLC Puncturing (Continued)

where

$$\bar{r}_u = \frac{1}{n} \sum_{n,m,l} \left( \alpha_{u,n,l} - \sum_v \beta_{v,u,n,m,l} \right) \frac{\tau_{u,n,l}}{m}, \quad \forall u \quad (8)$$

$$r_{v,n,m} = \sum_{u,l} \beta_{v,u,n,m,l} \tau_{v,n,m}, \quad \forall v, \forall n, \forall m \quad (9)$$

$$\tau_{v,n,m} = \min_l \{ \tau_{v,n,m,l} \}, \quad \forall v, \forall n, \forall m \quad (10)$$



# Channel Model – Path Loss and Shadowing

- Large-scale propagation path loss model (power in  $W$ )

$$\frac{p_{tx}}{p_{rx}(f, d)} = h(f, d) \quad (11)$$

$$p_{rx}^{dB}(f, d) = p_{tx}^{dB} - h^{dB}(f, d) \quad (12)$$

- Close-in (CI) free space reference distance model

$$h^{dB}(f, d) = 20 \log_{10} \frac{4\pi f}{3 \cdot 10^8} + 10\epsilon_{pl} \log_{10} d + \sigma_{sd}^{dB} \quad (13)$$

- Path loss exponent and shadowing standard deviation for urban macro-cellular (UMa) line-of-sight (LoS) over frequency and 3D distance ranging from 2 to 73.5GHz and 58 to 930m are derived as [2]

$$\epsilon_{pl} = 2 \quad (14)$$

$$\sigma_{sd}^{dB} = 4.6 \quad (15)$$

# Channel Model – Co-channel Interference and Thermal Noise

- Shannon-Hartley theorem (bandwidth in Hz, time in s)

$$r_{u,n,l} = w_{sc} \log_2 \left( 1 + \frac{p_{rx}^{dB}(f_l, d_{u,n})}{i_l^{dB} + o_{sc}^{dB}} \right) t_{sl} \left[ \frac{bits}{slot} \right],$$

$$\forall u, \forall n, \forall l$$

$$r_{v,n,m,l} = w_{sc} \log_2 \left( 1 + \frac{p_{rx}^{dB}(f_l, d_{v,n,m})}{i_l^{dB} + o_{sc}^{dB}} \right) t_{ms} \left[ \frac{bits}{minislot} \right],$$

$$\forall v, \forall n, \forall m, \forall l$$

- where

$$t_{ms} = \frac{t_{sl}}{m} \quad (16)$$

- Channel fading and inter-symbol interference (ISI) are not considered.

- [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: 10.1287/opre.1040.0156.
- [2] Shu Sun et al. “Propagation Path Loss Models for 5G Urban Micro- and Macro-Cellular Scenarios”. In: *2016 IEEE 83rd Vehicular Technology Conference (VTC Spring)*. 2016, pp. 1–6. DOI: 10.1109/VTCSpring.2016.7504435.