Multiconnectivity Based Joint Scheduling of URLLC and eMBB Traffic in 5G Networks

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Scenario 2: Neighborhood

- There are 2,000 households (up to 8,000 eMBB users e.g. downloading files, watching YouTube, surfing Facebook/Instagramm, etc.)
- During work hours and at night, there are only a few URLLC autonomous cars moving around
- Downlink transmission accounts for eMBB users' requests and URLLC autonomous cars' controlling
- Uplink transmission (whose bandwidth is separated from that of downlink) is responsible for uploading cars' data (e.g. camera images, GPS, sensors data, etc.) to server for navigation processing

Scenario 3: Hotel

- There are 10 rooms (up to 40 eMBB users) in a floor
- There are 2 URLLC service robots delivering food and miscellaneous items
- Downlink transmission accounts for eMBB users' requests and URLLC service robots' controlling
- Uplink transmission (whose bandwidth is separated from that of downlink) is responsible for uploading robots' data (i.e. camera images, sensors data, etc.) to server for navigation processing

Problem Statement

- Downlink transmission is considered
- Problems:
  - One base station cannot serve that many eMBB users due to bandwidth limitation
  - eMBB users located at base stations' coverage edges suffer from poor capacity due to path loss, channel fading, and shadowing (especially if mmWave is employed)
- Solution: Multiconnectivity for eMBB user equipments (assume URLLC user equipments have only 1 antenna and always connect to their closest base station)
- Motivation:
- Pros and Cons:
  - (+) Resolves the aforementioned issues
  - (-) Interference among base stations needs to be addressed
  - (-) Requires eMBB user equipments to support MIMO (Multiple-Input and Multiple-Output)

eMBB & URLLC Interference Problem of Multicell

- eMBB interference problem: Even without taking URLLC user equipments into account, interference may occur among eMBB user equipments of *different* base stations
- URLLC interference problem:
  - If for each base station, the same dedicated channel is allocated for URLLC traffic, then interference may occur among URLLC user equipments of *different* base stations
  - If for all base stations, mutually exclusive dedicated channels are allocated for URLLC traffic, then interference may occur between URLLC user equipments of one base station and eMBB user equipments of others
  - If URLLC puncture system is used on all base stations, then interference may occur between URLLC user equipments of one base station and eMBB/URLLC user equipments of others

eMBB & URLLC Interference Problem of Multicell

- Solution 1: Mathematical optimization with optimal analysis (currently researching [2])
- Solution 2: Approximation algorithm with approximation ratio analysis (currently researching [1])

eMBB & URLLC Interference Problem of Multicell

- Solution 3: W-CDMA (Wideband Code Division Multiple Access)
- Motivation: LEACH (Low-Energy Adaptive Clustering Hierarchy)
- Pros and Cons:
  - (+) Preserves the full spectral resource
  - (+) Fits with the often small number of base stations
  - (+) Simplifies the mathematical model of the system
  - (-) Introduces redundant bits
  - (-) Requires eMBB user equipments to support *multiple* CDMA
  - (-) Requires URLLC user equipments to support CDMA
- However, the number of redundant bits required is the number of orthogonal basis to assign to each base station i.e. the number of base stations, which is negligible
- On the other hand, it is projected that devices are becoming more and more advanced, so expecting user equipments to support multiple CDMA at the same time is plausible

Spectral Utilization Problem of Dedicated URLLC Channel

- If a bandwidth $\mathfrak{w}$ is dedicated to serve URLLC requests, a total of $\mathfrak{w} \times \mathfrak{b}$ bandwidth is wasted, where $\mathfrak{b}$ is the number of base stations
- Solution: URLLC superposition/puncturing
- Motivation:
- Pros and Cons:

RB-Wise Interference Problem of URLLC Superposition

- If URLLC superposition system is used, then interference is guaranteed to occur between eMBB and URLLC user equipment of the same resource block (RB)
- Solution: URLLC puncturing
- Motivation: [4]
- Pros and Cons:

System Model

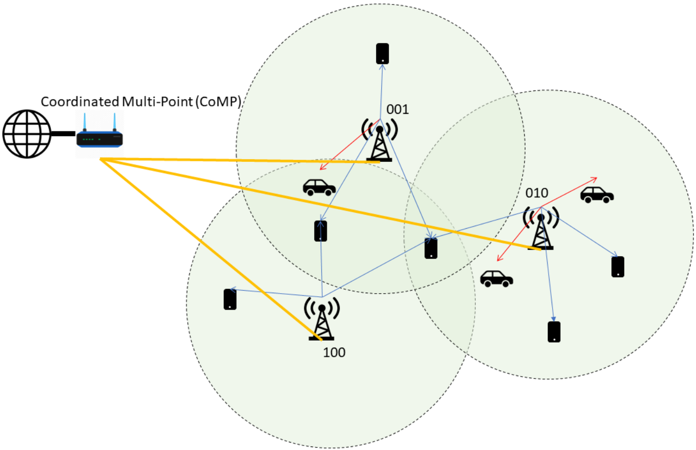

Figure: System model

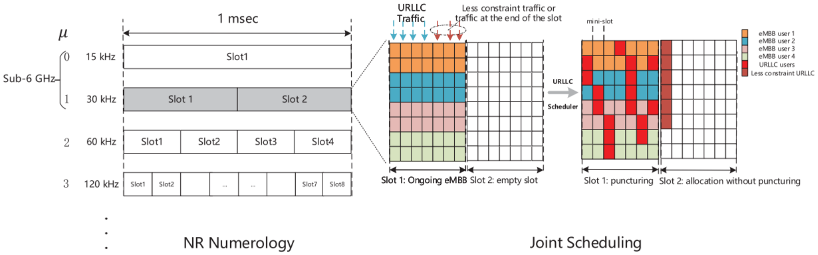

Figure: System framework [3]

References

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[3] Hao Yin, Lyutianyang Zhang, and Sumit Roy. "Multiplexing URLLC Traffic Within eMBB Services in 5G NR: Fair Scheduling". In: *IEEE Transactions on Communications* 69.2 (2021), pp. 1080–1093. DOI: 10.1109/TCOMM.2020.3035582.

[4] Kai Ying et al. "Coexistence of enhanced mobile broadband communications and ultra-reliable low-latency communications in mobile front-haul". In: *Broadband Access Communication Technologies XII*. Ed. by Benjamin B. Dingel, Katsutoshi Tsukamoto, and Spiros Mikroulis. Vol. 10559. International Society for Optics and Photonics. SPIE, 2018, pp. 56–62. DOI: 10.1117/12.2287563. URL: https://doi.org/10.1117/12.2287563.