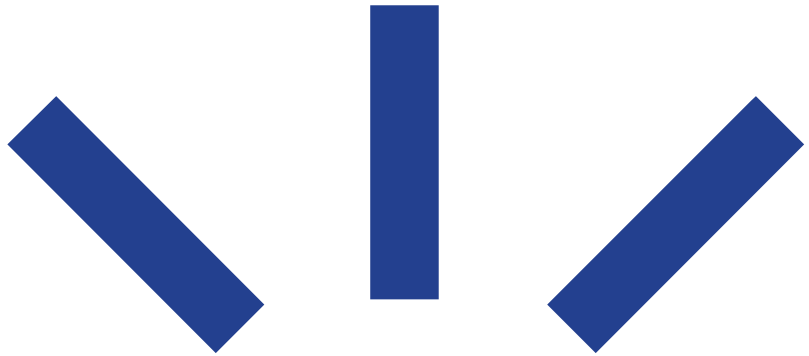

Coded Caching for Future Improved Networking (CC-FIN)

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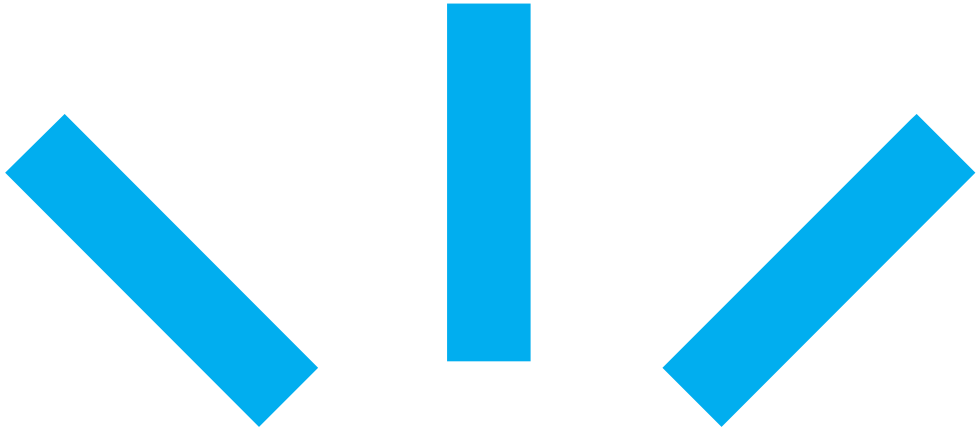
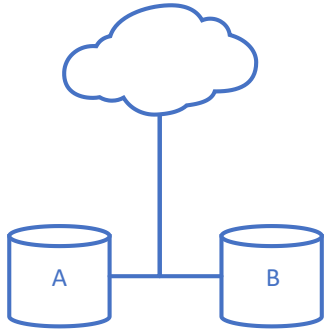


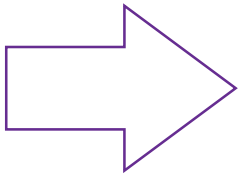
The Introduction

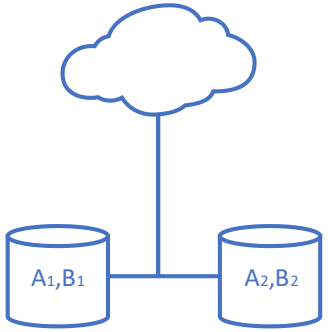
Coded Caching and its example Applications

Coded Caching



Request 1	Request 2	Load
A	B	0
B	A	2
A	A	1
B	B	1
Average Load		1





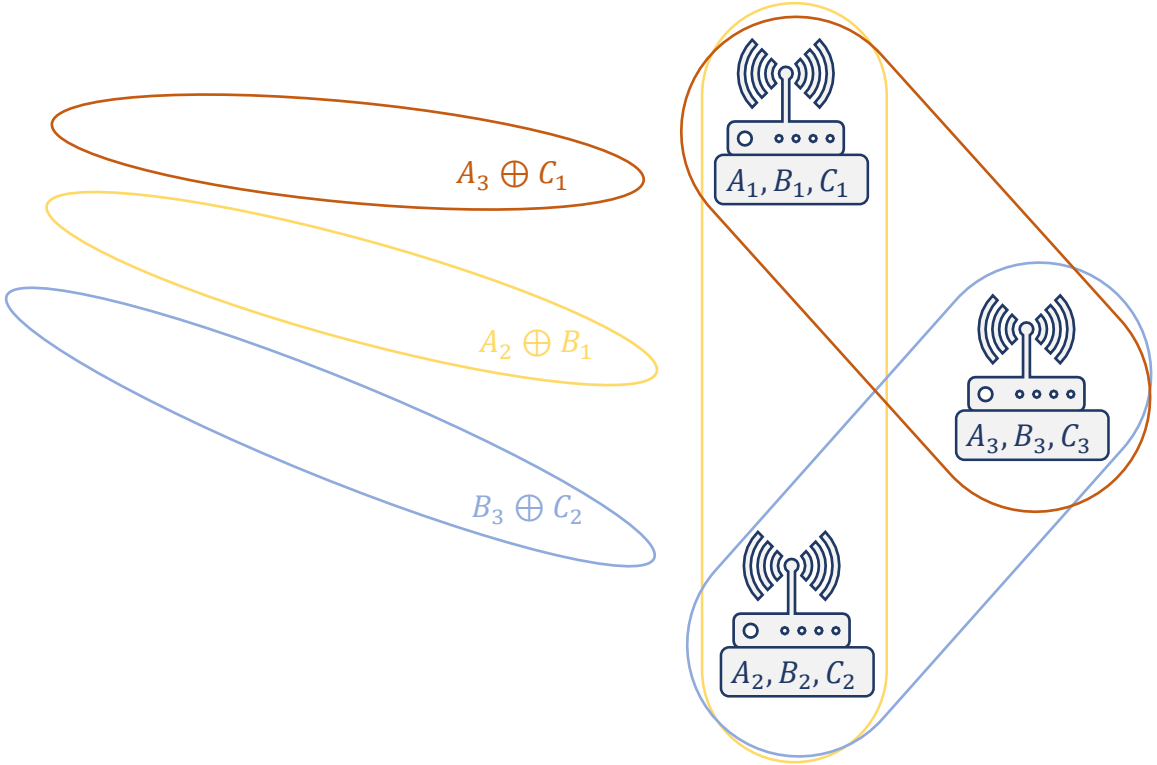
Request 1	Request 2	Codeword	Load
A	B	$A_2 \oplus B_1$	0,5
B	A	$B_2 \oplus A_1$	0,5
A	A	$A_2 \oplus A_1$	0,5
B	B	$B_2 \oplus B_1$	0,5
Average Load			0,5

Coded caching enables a load reduction by a factor of $t + 1$, where $t = KM/N$.

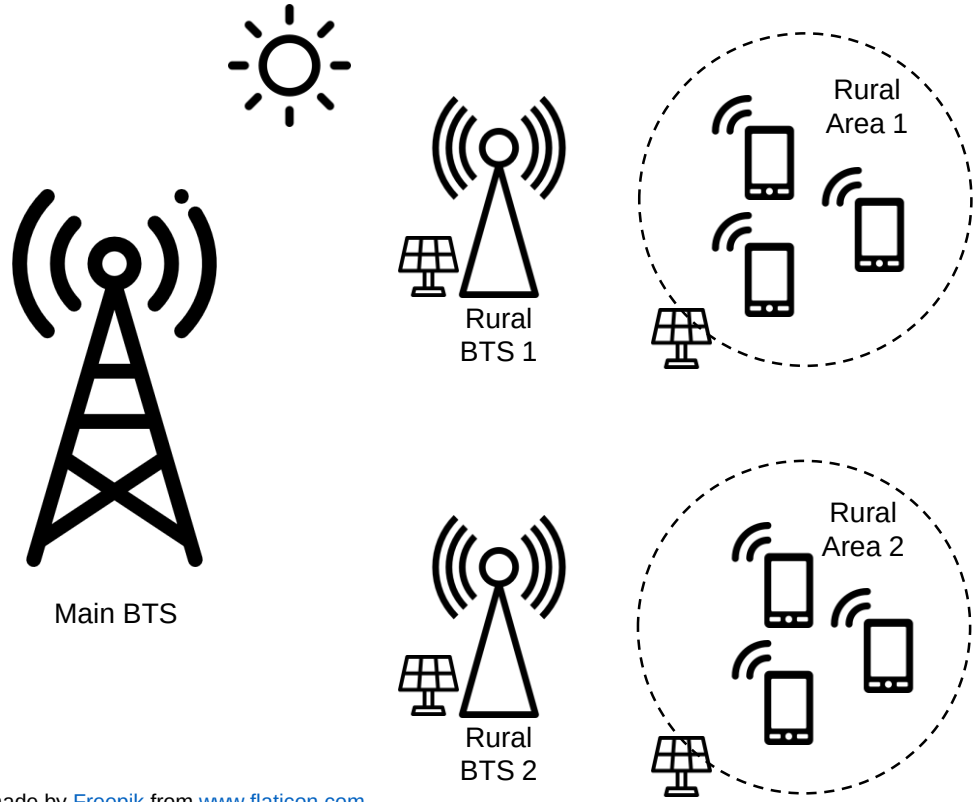
Multi-Antenna Coded Caching

- **Coded caching gain is additive with the spatial multiplexing gain.**
- **In case of L antennas, the cumulative DoF of $t + L$ is achievable.**

$$\boldsymbol{x} = (A_2 \oplus B_1)\boldsymbol{w}_3 + (A_3 \oplus B_1)\boldsymbol{w}_2 + (B_3 \oplus C_2)\boldsymbol{w}_1$$



Application: Rural Connectivity

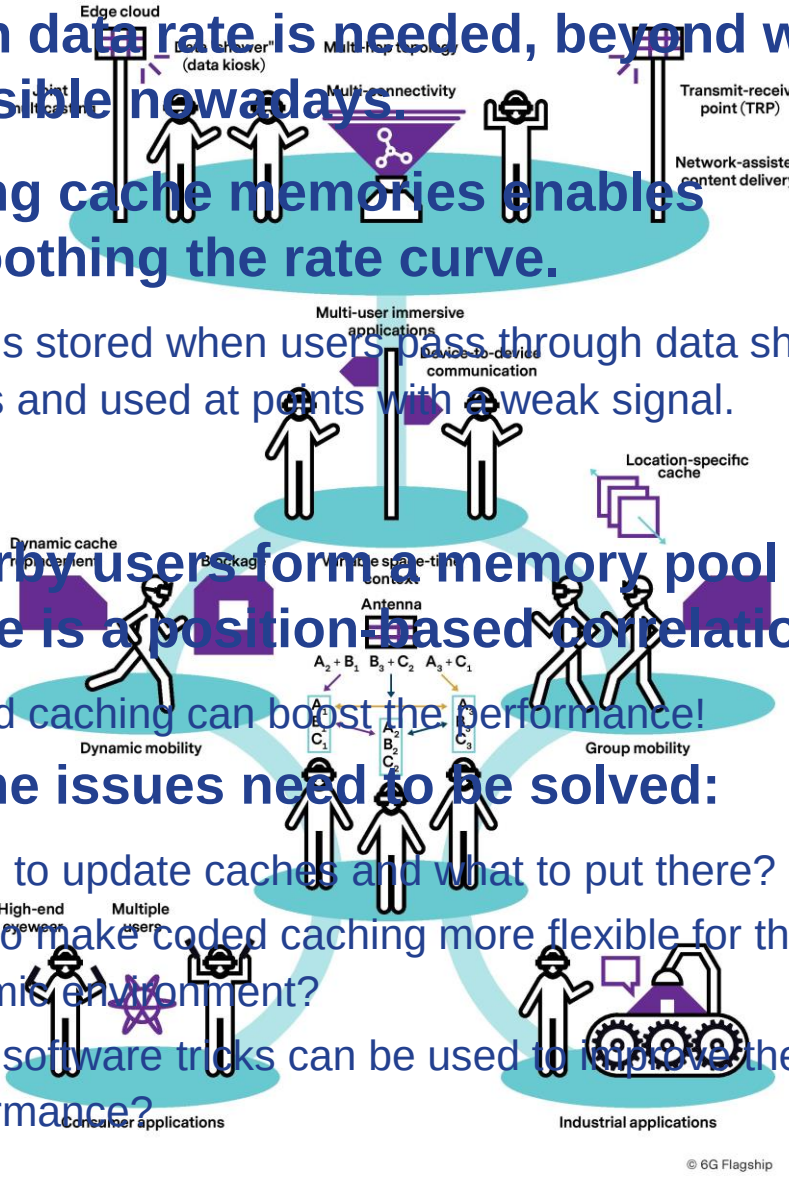


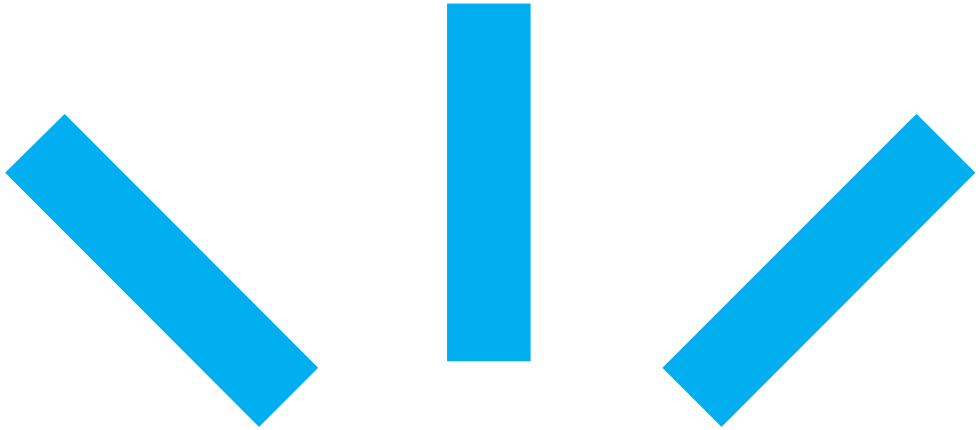
*Icons made by Freepik from www.flaticon.com

- **Network elements may be powered by unreliable harvested energy.**
- **Excess energy, when available, can be used to fill up the cache memories.**
  - We aim at storing energy in the form of data bits.
- **There exist memory pools at various levels:**
  - Nearby users in a rural area, nearby rural base stations, or a mixture of both.
- **Coded caching can be used to improve the performance.**
- **Some issues need to be solved:**
  - Tailoring coded caching with unreliable energy availability.
  - Tailoring coded caching with different communication strategies.
  - Using energy/data predictions to boost the performance.

Application: Immersive Viewing

- **High data rate is needed, beyond what's possible nowadays.**
- **Using cache memories enables smoothing the rate curve.**
  - Data is stored when users pass through data shower points and used at points with a weak signal.
- **Nearby users form a memory pool and there is a position-based correlation.**
  - Coded caching can boost the performance!
- **Some issues need to be solved:**
  - When to update caches and what to put there?
  - How to make coded caching more flexible for this dynamic environment?
  - What software tricks can be used to improve the performance?





Research Directions

The Issues that Need to be Solved

The Subpacketization Bottleneck

$$S_{MN} = \binom{K}{t}$$

Maddah-Ali, M.A. and Niesen, U., 2014. Fundamental limits of caching. *IEEE Transactions on Information Theory*, *60*(5), pp.2856-2867.

$$S_{MS} = \binom{K}{t}\binom{K-t-1}{L-1}$$

Shariatpanahi, S.P., Motahari, S.A. and Khalaj, B.H., 2016. Multi-server coded caching. *IEEE Transactions on Information Theory*, *62*(12), pp.7253-7271.

$$\frac{t}{L}, \frac{K}{L} \in \mathbb{Z}^+ \Rightarrow S_{LE} = \binom{K/L}{t/L}$$

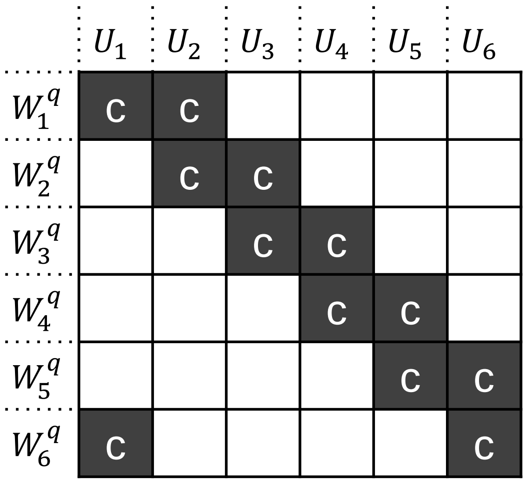
Lampiris, E. and Elia, P., 2018. Adding transmitters dramatically boosts coded-caching gains for finite file sizes. *IEEE Journal on Selected Areas in Communications*, *36*(6), pp.1176-1188.

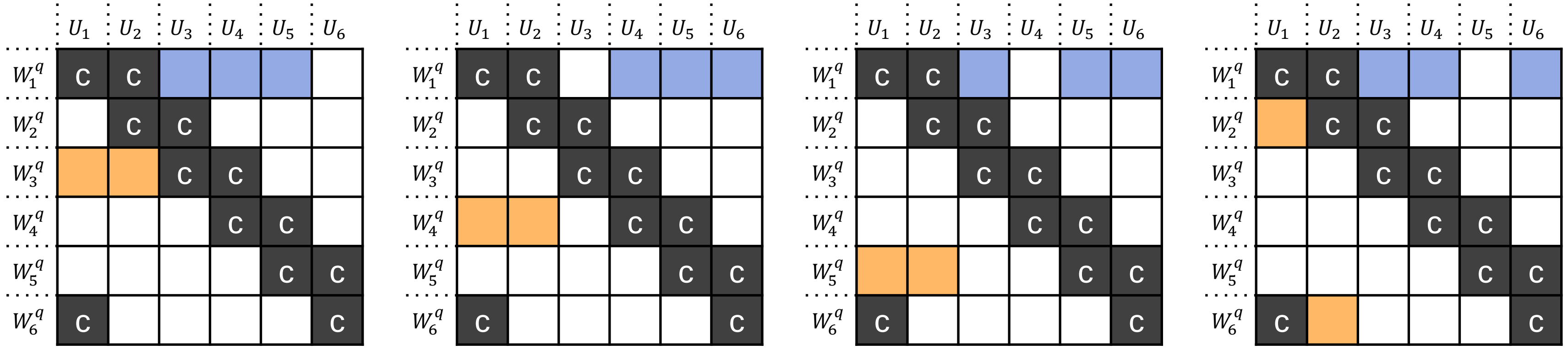
- **Subpacketization S is defined as the number of smaller parts each file should be split into.**
- **Well-known coded caching schemes suffer from exponentially growing S.**
- **In single-antenna coded caching, it is not possible to reduce S considerably.**
- **Multi-antenna coded caching is more flexible!**

The Subpacketization Bottleneck

- If $L \geq t$, the linear subpacketization of $K(t+L)$ is achievable without DoF loss.
- The subpacketization can be further reduced to:

$$S_{min} = \frac{K}{\gcd(K,t)} \times \frac{t+L}{\gcd(K-t,t+L)}$$





Salehi, M., Tölli, A. and Shariatpanahi, S.P., 2020, June. A multi-antenna coded caching scheme with linear subpacketization. In *ICC 2020-2020 IEEE International Conference on Communications (ICC)* (pp. 1-6). IEEE.

- Setting spatial multiplexing gain to $t \leq \alpha \leq L$, we control subpacketization and also improve the finite-SNR performance.

Multicast Beamforming

- **Designing optimized multicast beamformers is generally complex.**
- **Zero-forcing results in poor performance.**
- **Two possible solutions:**
  - Try zero-forcing with reduced spatial multiplexing gain;
  - Try optimized beamformers with caching gain but with reduced multicasting gain.

Tölli A, Shariatpanahi SP, Kaleva J, Khalaj BH. Multi-antenna interference management for coded caching. IEEE Transactions on Wireless Communications. 2020 Jan 6;19(3):2091-106.

Salehi M, Parrinello E, Shariatpanahi SP, Elia P, Tölli A. Low-Complexity High-Performance Cyclic Caching for Large MISO Systems. arXiv preprint arXiv:2009.12231. 2020 Sep 25.

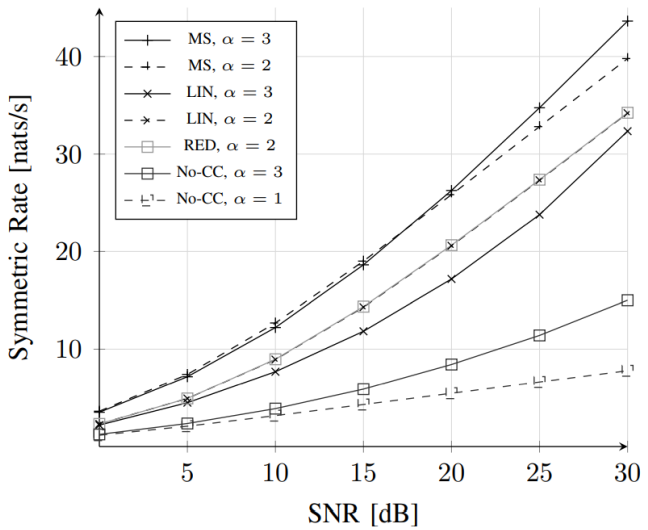


Fig. MS vs LIN vs RED vs No-CC rate; $K = 6$, $t = 2$, $L = 3$

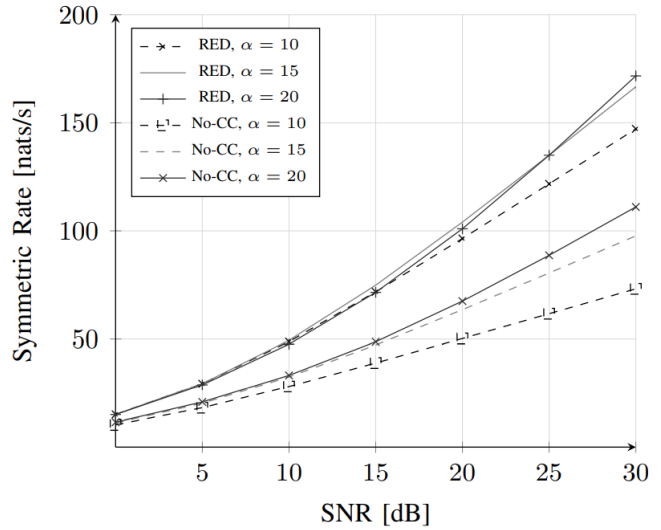
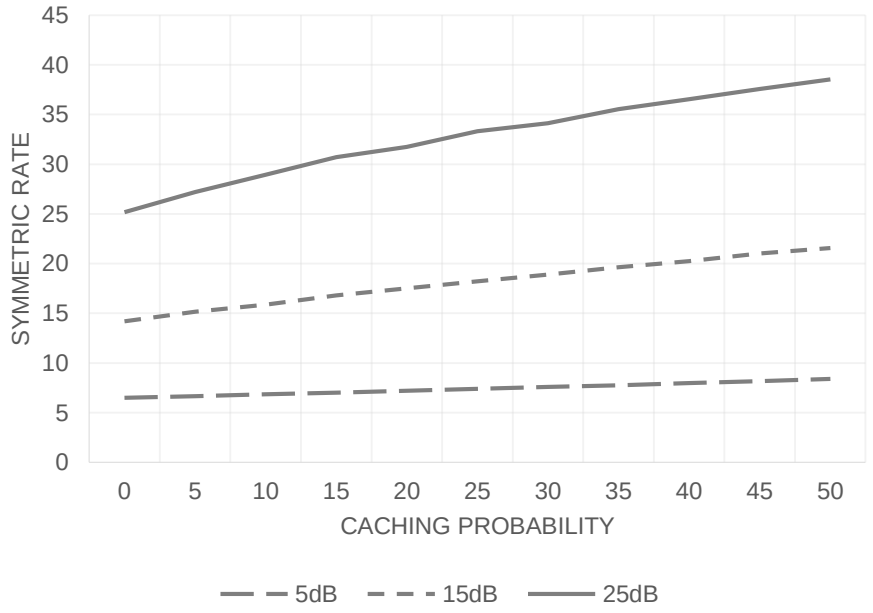


Fig. Performance of RED, $K = 100$, $t = 10$, $L = 25$

Strict Cache Placement Phase



- **Coded caching schemes are strictly dependent on a well-performed cache placement phase.**
  - Not suitable for dynamic environments such as the immersive viewing example.
  - Not suitable for unreliable connectivity environments such as the rural connectivity example.

- **A solution may be possible by relying on probabilisitc cache placement.**
  - An opportunistic approach!
  - The first stages of development.
  - Can be combined by movement/energy predictions for improved performance.

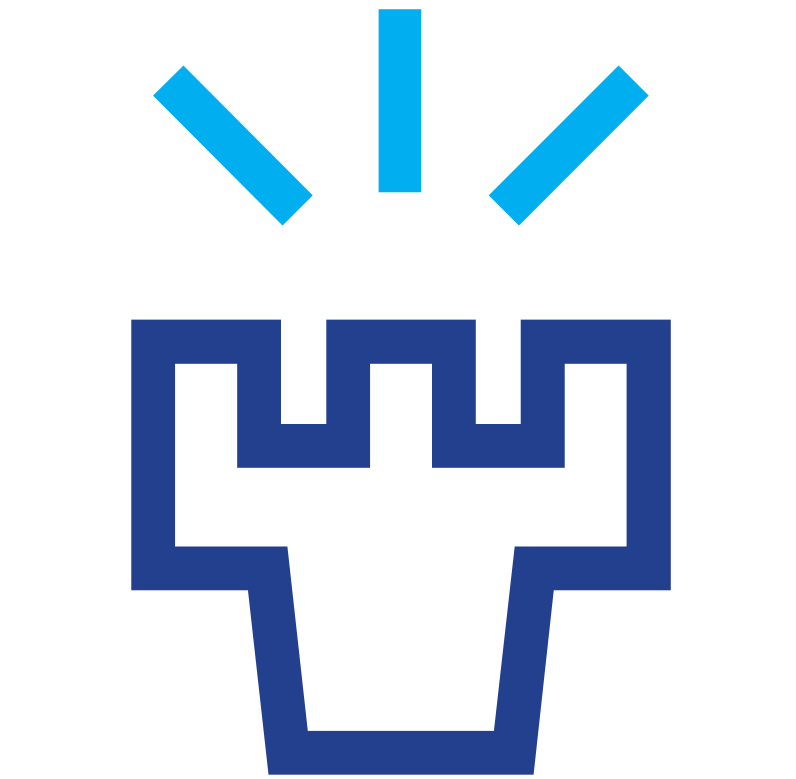
Some Other Issues

- **Some assumptions need to be relaxed for a real-world implementation.**
- **File request probability at each user may be:**
  - Different from other users,
  - Dependent on the request probability of other users,
  - Predictable to various levels.
- **Equal file size in unrealistic. Splitting files into equal-sized parts creates correlation.**
- **Coded caching needs to be studied under extreme conditions:**
  - DoF is much larger than the user count (e.g. large antenna arrays),
  - Very small or very big file library.

Summary

Summary

- **Coded caching is an interesting tool for increasing data rate in future networks.**
- **It works when a memory pool is available. For example:**
  - Improved rural connectivity,
  - Improved immersive viewing.
- **We need to solve important issues for practical implementation to be possible:**
  - The subpacketization bottleneck,
  - Multicast beamforming for coded caching,
  - Opportunistic coded caching,
  - Relaxing unrealistic assumptions,
  - Addressing extreme cases.
- **Notable research opportunity!**



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