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On the Technical Misconceptions of Wireless Edge Caching

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I. EXTENDED ABSTRACT

Caching is a hot research topic and poised to develop into a key technology for the upcoming 5G wireless networks. The successful implementation of caching techniques however, crucially depends on joint research developments in different scientific domains such as networking, information theory, machine learning, and wireless communications. Moreover, there exist business barriers related to the complex interactions between the involved stakeholders, the users, the cellular operators, and the Internet content providers. In this article we discuss several technical misconceptions with the aim to uncover enabling research directions for caching in wireless systems. Ultimately we make a speculative stakeholder analysis for wireless caching in 5G.

A. Dealing with Massive Content:

1) *Content Popularity Is Not Static:* Recent studies consider large samples of YouTube and Video on Demand (VoD) applications and discover: content popularity is time-varying and in addition has a consistent effect on analyzing the caching performance. In this regard, time-varying content popularity models, such as Shot Noise Model (SNM), are more accurate than Independence Reference Model (IRM) with respect to caching performance analysis—see Figure 1.

2) *Spatio-temporal Popularity Variations Can Be Accurately Tracked:* Since content popularity is time-varying, the caching operations can only be optimized if a fresh view of the system is maintained. This requires massive data collection and processing, and statistical inference from this data, which by itself is a complex task to handle. Additionally, user privacy is a concern that can limit the potential of collecting such information. Despite these facts, it is possible to timely gather all this information in a wireless network [3].

3) *Security Is A Kind of Death:* A common anti-caching argument relates to the operation of caching in a secure environment. The secure counterpart of HTTP protocol, called

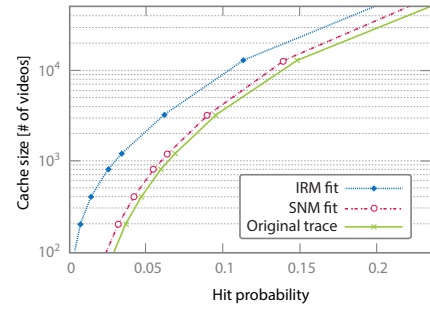


Figure 1: (from [2]) Hit probability comparison between best fit of IRM, SNM and the YouTube traces.

HTTPS, was originally used to provide end-to-end (e2e) encryption for securing sensitive information like online banking transactions and authentication. Owing to the recent adoption from traffic giants Netflix and YouTube, the HTTPS protocol is growing in numbers to soon exceed 50% of the total network traffic. Content encryption poses an unsurmountable obstacle to in-network operations, including caching. Since encrypting the data makes them unique and not reusable, caching, hitting, or even statistically processing encrypted content is impossible. Ironically, the statement “security is a kind of death” of Tennessee Williams seems to squarely apply to wireless caching. An approach (which also represents an interesting direction of research) is that of adopting a different security protocol, one that could enable the operators to perform caching on encrypted requests [4].

B. Towards a Unified Network Memory:

1) *Caching at CDN-level Is Not Enough:* The congestion in backhaul and wireless links can be avoided only if we cache near the user, so if we are to use caching to improve the sustainability of 5G systems, caching at the wireless access is necessary. However, the detection of users’ content requests/activities is also crucial and depends on the number of requests aggregated at the popularity learner. To illustrate

this, Figure 2 shows the optimal hit probability in a hierarchy of L base stations.

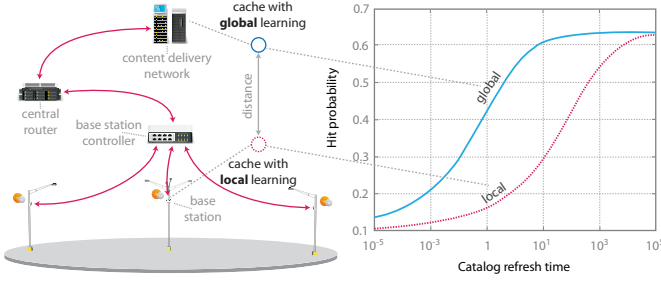


Figure 2: Optimal hit probability comparison between observing the aggregate request process at the CDN-level (global), and observing the individual request process at each base station cache (local). The hit probability loss is attributed to the sparsity of content requests.

2) *Memory Should Be Deployed Where Needed:* Stochastic geometry modeling and analysis can be used to find optimal cache deployments, as shown in Figure 3.

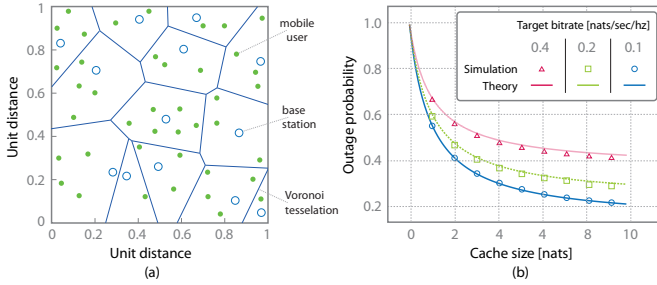


Figure 3: An example of base station deployment with caching capabilities [5]: (a) illustrates a snapshot of 2D topology in which users and cache-enabled base stations are distributed according to Poisson Point Processes (PPPs), (b) shows theoretical performance gains of such a deployment, where the validation of results is done via simulations.

C. Wireless \neq Wired:

1) *Wireless Caching Lies Both at Network and PHY Layers:* The coded caching scheme is shown in [6] to yield required resource blocks equal to $K(1 - M/N)/(1 + KM/N)$, where K is the number of users, M the cache size, and N the catalog size. Hence, if the cacheable fraction of the catalog M/N is kept fixed, then the required number of resource blocks does not increase with the number of users K , this can be verified by taking the limit $K \rightarrow \infty$ whereby the above quantity converges to a constant. The result is pictorially summarized in Figure 4.

2) *One Cache Analysis Is Not Sufficient:* A contemporary mobile receives the signal of more than 10 base stations simultaneously. In future densified cellular networks, the mobile will be connected to several femto-, pico-, or nano- cells. The phenomenon of wireless multi-access opens a new horizon in caching exploitation [7].

D. A Stakeholder Analysis for Wireless Caching:

The business of wireless caching involves three key stakeholders that together form a complex ecosystem: users, oper-

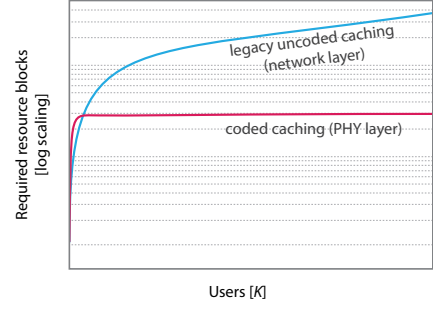


Figure 4: Required resource blocks for K mobile users with unicast demands, when the caches fit 30% of the catalog. Coded caching can serve an arbitrarily large population of users with a fixed number of resource blocks.

ators and content providers. We summarize what each stakeholder *offers* and *needs* in Figure 5.

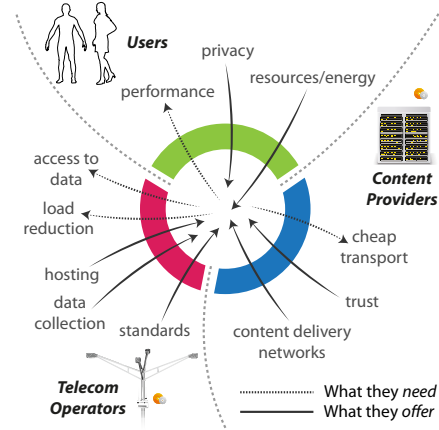


Figure 5: A stakeholder analysis.

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