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Exploring mobile OTT service user's psychological resistance toward wireless mobile caching networks and telecommunication operator's incentive policy, using agent-based model scenarios.

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Keywords: OTT service, mobile caching, ABM

Introduction

The rapid integration of mobile Over-The-Top (OTT) services into daily life, driven by advancements in mobile technology and changing consumption patterns, has led to a significant increase in mobile data traffic. This surge, particularly evident in South Korea, has been fueled by the widespread consumption of OTT video content on mobile devices, challenging the existing broadband network infrastructure (KCC, 2020). Despite advancements in mobile communication technologies, such as improved picture quality and faster data transmission speeds, the rising demand for video streaming has revealed the limitations of current network capacities (Richter, 2022). Moreover, the introduction of 5G technology, while promising, has not fully satisfied user expectations, underscoring the urgent need for innovative solutions to address these challenges.

Wireless mobile caching networks emerge as a promising alternative, aiming to alleviate network congestion by pre-storing content on devices during off-peak hours and facilitating content sharing among users (Zhang et al., 2019, Mohajer, 2020). This approach significantly alleviates the overload of wireless access links by pre-storing content in users' storage during non-peak hours and providing content-sharing services to pairs of users who are near each other during peak hours (Yao et al., 2019).

The commercialization of wireless mobile caching networks heavily relies on user support due to the resource demands of this technology. Users are required to allocate their device storage for pre-storing video content, and content sharing

between users depletes the battery of their mobile devices (Huang et al., 2020). Consequently, these requirements may lead to psychological resistance towards embracing mobile caching technology (Jang et al., 2024). To mitigate this resistance, mobile caching operators can offer a range of incentives to encourage user participation (Zhou et al., 2021).

Based on the above discussion, this study first investigates whether mobile OTT service users' willingness to allocate device storage for adopting wireless mobile caching networks is influenced by various levels of incentives. This study also aims to understand the functions related to adopting wireless mobile caching networks by analyzing these decision-making processes with Agent-Based Modeling (ABM) (Wilensky, 2015). By combining the analysis of incentives' effects with ABM, the study will propose strategies to promote the commercialization of wireless mobile caching networks and introduce a novel approach for policy development in the telecommunications field. To achieve these goals, this study presents the following research questions:

RQ1. How do mobile OTT service users perceive the adoption of wireless mobile caching networks on their mobile devices and incentive policies?

RQ1-1. How much resources, such as mobile device storage and the battery, can users provide for adopting wireless mobile caching networks?

RQ1-2. What kinds of and how much incentives do users think it is appropriate to be provided?

RQ2. How can an incentivized mobile

caching strategy be applied to effectively manage OTT video data traffic?

RQ2-1. Is mobile caching effective in reducing OTT video data traffic?

RQ2-2. How do incentivized caching networks affect OTT video data traffic?

Literature review

OTT service refers to a video content streaming service delivered over a public network (Fautier, 2020). Unlike traditional broadcasters or ISPs, OTT platforms operate independently, using Internet Protocol (IP) (Tadayoni & Henten, 2013). The appeal of OTT service lies in its ability to offer users convenient access to video content anytime, anywhere, and on any device, leading to widespread adoption globally, including in Korea (Mulla, 2020).

The OTT market in Korea has seen significant growth and competition, with platforms like Netflix, Disney+, and Tving vying for subscribers. OTT platforms rely on telecommunication operators' broadband, and as more users watch OTT content on smartphones, network traffic from global giants like Netflix and YouTube has surged (KCC, 2020). In Korea, over two-thirds of Koreans subscribe to paid OTT services, generating substantial daily mobile data traffic (Mohajer, 2020). The traffic share from these companies rose from 33.9% in 2020 to 37.8% in 2021 (Kang, 2022).

Despite advancements like 4G and 5G, current mobile technology struggles with high network traffic demands (Mulla, 2022). Operators are working to improve service quality by expanding network bandwidth and building more base stations but face challenges like high costs, limited resources, and government restrictions (Mohajer, 2020). Thus, operators need new technological solutions to address these issues.

Data traffic is not uniform over time, with peak-hour demands causing significant congestion (Paul et al., 2011). The increasing requests for high-quality OTT services exacerbate this issue. One promising solution is wireless mobile caching

networks, which alleviate overload by pre-storing content during non-peak hours and sharing it among nearby users during peak hours (Mulla, 2022).

Wireless mobile caching networks reduce data traffic by storing popular content in users' devices and enabling direct sharing, decreasing duplicate requests (Zhang et al., 2019). The effectiveness of this approach is proportional to the storage size users allocate (Chen et al., 2018). The increasing storage capacity of mobile devices enhances the feasibility of this solution (Bastug et al., 2015).

Device-to-device (D2D) communication is crucial for this system, allowing users in close proximity to share content directly, thus mitigating network traffic (Mohajer, 2020). High-density areas offer more opportunities for D2D links, significantly reducing transmission costs and bandwidth usage (Ibrahim et al., 2020).

Methodology

The methodology of this study is centered on assessing the viability and effectiveness of mobile caching in wireless networks in South Korea. It utilizes a mixed-methods approach, starting with an online survey to gather data on demographics, mobile usage patterns, and willingness among smartphone users to allocate storage for caching purposes. This survey aims to understand user predispositions towards utilizing their device storage for caching, which could alleviate network traffic. Following the survey, the study employs (ABM) to simulate the behaviors of individuals within these networks (Wilensky, 2015). ABM allows for a detailed examination of how users, acting as agents, interact with one another and the network, specifically focusing on content sharing and its potential to reduce overall network traffic. The simulation explores various scenarios to assess how different incentive policies might influence user behavior and network performance, aiming to offer evidence-based recommendations for policy formulations in D2D communication settings.

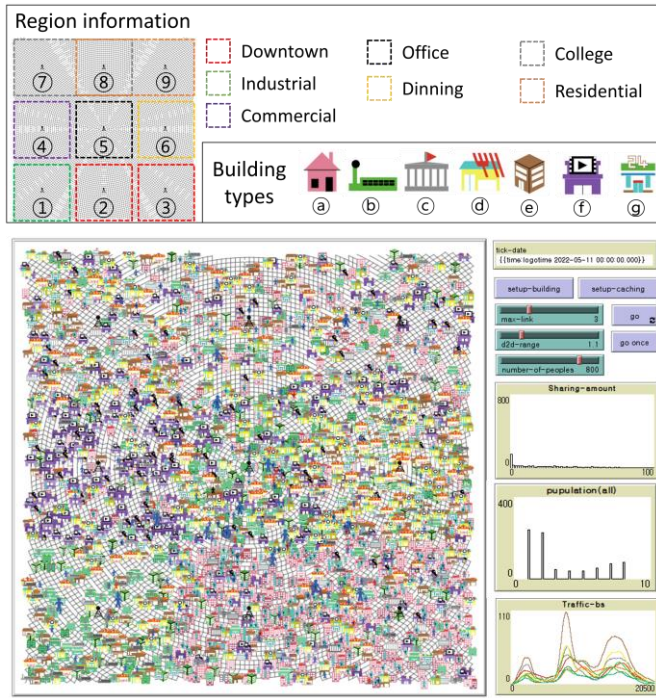


Figure 1 Netlogo implementation of urban environment.

In the ABM model, agents represent different types of individuals with specific daily routines. Office workers follow a set commute schedule, work during the day, take short breaks, have lunch near their office, and return home or engage in leisure activities in the evening. College students have schedules revolving around their classes. They attend courses, take breaks between classes, and spend time near the university before returning home or engaging in leisure activities. People with flexible schedules stay within their residential area, spending most of their time at home or engaging in leisure activities.

The system space consists of various urban areas and buildings. This study models a simplified urban environment with seven types of buildings, representing nine typical urban areas. The detailed physical layout is simplified to manage memory and computation efficiently (Nguyen et al., 2012). The implementation of this urban environment in NetLogo is depicted in figure 1.

The environment includes factors influencing agent behavior and system dynamics, such as OTT viewing patterns, wireless caching networks, and incentive policies. Agents watch

and share content while moving, eating, and during breaks. Content is pre-stored in agents' storage via base stations at the start of the day. Agents share this content with others within a specific communication radius through D2D links. The formation of D2D links indicates that a user's desired content matches the content stored in the storage of the other user in the D2D pair. Sharing stops if agents move out of range, the battery is low, or after a certain time. Battery consumption is proportional to the number of active links, and it recovers when not viewing content. Incentives are determined by the volume of content shared throughout the day.

Results

Based on a comprehensive analysis of 312 responses to a survey on mobile OTT service usage, this study delves into several key aspects including subscription costs, and users' willingness to participate in wireless mobile caching networks. The profile of the respondents is presented in Table 1, which shows the following features: the number of mobile OTT services in use, most used mobile OTT service, age, and gender. On average, respondents subscribe 2.81 mobile OTT services and spend 16945.71KRW (12.28 USD) per month on subscription fee. individuals are willing to allocate between 15.67GB to 40.83GB of their mobile device storage for caching purposes. Respondents are willing on average, to provide as little as 15.67GB of memory and as much as 40.83GB of memory to adopt wireless mobile caching networks on their mobile devices.

Table 1. Sample characteristics (N=312)

Characteristics	Frequency	Valid percent
<i>Number of mobile OTT service in use:</i>		
1	92	29.5
2	45	14.4
3	24	7.7
More than 4		
<i>Most used mobile OTT</i>		

<i>service (multiple response):</i>	213	68.3
Netflix	28	9.0
Tving	26	8.3
Wavve	17	5.4
Coupangplay	15	4.8
Disney+	5	1.6
Watcha	3	1.0
AppleTV	2	0.6
Seezn	3	1.0
Others		
<i>Age:</i>		
20s	78	25.0
30s	80	25.6
40s	78	25.0
50s	76	24.4

RQ1-1. How much resources, such as mobile device storage and the battery, can users provide for adopting the wireless mobile caching networks?

Respondents are willing to provide at least an average of 15.67GB and at most an average of 40.83GB of storage when adopting wireless mobile caching networks on their mobile devices.

RQ1-2. What kinds of and how much incentives do users think it is appropriate to be provided?

In a survey, respondents chose 4 options among a total of 8 options which consist of 4 financial incentives and 4 social recognition related incentives. As table 2 shows, cash, mobile data plan cost incentive, additional offer of mobile data, and additional offer of points or mileage from telecommunication operator were most preferred. Overall, financial incentives were strongly preferred compared to social recognition related incentives.

Table 2. Preferred incentives (multiple answers)

Characteristics	N	%
Cash	266	21.3
Mobile data plat cost incentive	304	24.4
Additional mobile data	210	16.8
Mileage from operator	169	13.5
Title	67	5.4
SNS accessories	55	4.4
Merchandise	83	6.7

Sign with the name as a tree adopter	74	5.9
Others	20	1.6
Total	1248	100

When asked how much additional storage they can provide when incentives such as 3%, 5%, or 7% discount on mobile data rates are provided, respondents described that they could provide an average of 9.26GB of storage with a 3% discount, an average of 15.53GB of storage with a 5% discount, and an average of 23.67GB of storage with a 7% discount. It shows the tendency that the more storage the users provide, the more discount on mobile data rates the users want.

RQ2-1. Is mobile caching effective in reducing OTT video data traffic?

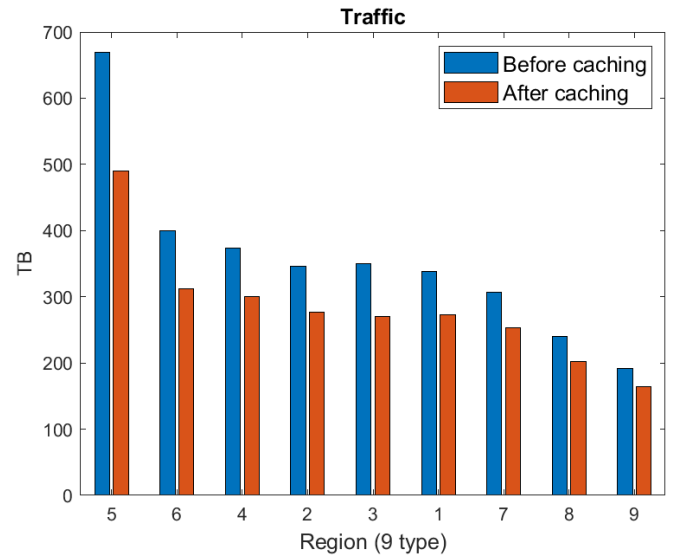


Figure 2 Traffic comparison before and after caching

Figure 2 compares the traffic before and after caching across nine different regions. The data traffic volume is displayed in terabytes (TB) and is sorted in descending order along the horizontal axis, with regions experiencing higher data traffic appearing first. The office area (Region 5) exhibits approximately three times more data traffic compared to the residential area (Region 9), which has the lowest traffic. This significant difference indicates a high concentration of users passing through or staying within the office area throughout the day, resulting in substantially increased data traffic compared to

other regions. While there are variations among regions, caching achieves an average traffic reduction of 19.79%. The most prominent reduction is observed in the office area (Region 5), with a decrease of approximately 26.81% from 669.27 TB to 489.81 TB. These observations suggest that while the amount of user-generated traffic varies by region, caching is particularly effective in densely populated areas.

RQ2-2. How do incentivized caching networks affect OTT video data traffic?

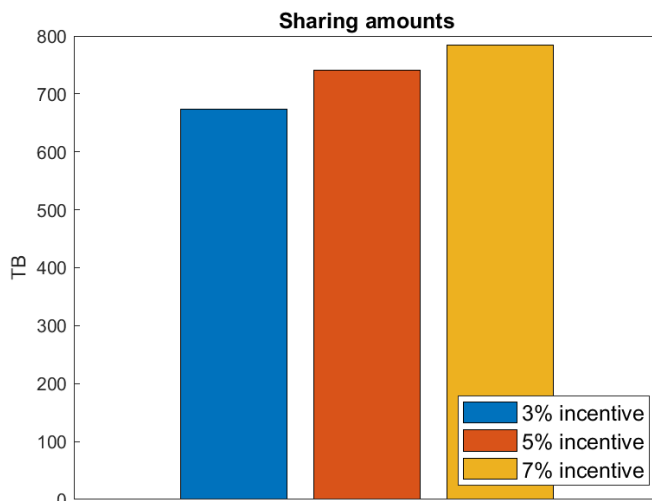


Figure 3 Sharing amounts with three different incentive cases

Figure 3 displays the amount of sharing data transmitted through D2D communication within a mobile caching network over a single day, categorized by different incentives (3%, 5%, 7%) based on data plans. The 3% incentive facilitates the sharing of 674.04TB of content between users. When the incentive is increased to 5%, the amount of shared data rises to 740.34TB, marking a 9.79% increase compared to the 3% incentive plan. This upward trend continues with the 7% incentive, where the amount of shared data reaches 784.88TB, reflecting a 16.44% increase over the base level of the 3% incentive. Providing higher incentives encourages users to store more content, which in turn amplifies the amount of content available for sharing and enhances the likelihood of sharing.

Conclusion

This research investigates the potential impact of incentivized mobile caching on managing OTT video data traffic. By conducting an survey, the study assessed user perceptions and willingness to allocate storage for mobile caching, providing significant insights into how much storage users are willing to lend. The subsequent simulations using NetLogo examined the empirical effects of caching on data traffic reduction, factoring in different incentive levels. The results demonstrated that incentivized mobile caching could lead to reductions in data traffic.

The findings suggest that encouraging users to share content locally through their devices can alleviate network congestion, enhance streaming quality, and reduce buffering times. This approach not only improves network efficiency but also potentially enhances the user experience. However, the process of pre-storing and sharing content raises privacy concerns. Effective methods for protecting personal information are essential to achieve traffic reduction and encourage widespread adoption of the technology (Kondor et al., 2018).

One key implication is that mobile caching can mitigate the conflict between Mobile telecommunication operators and OTT platforms by managing network congestion more effectively. By pre-storing and sharing content, this approach reduces traffic load without requiring additional infrastructure investment, benefiting both parties. Traffic reduction effects vary by region, indicating that pilot caching programs could first be applied in high-traffic office areas. The incentive model based on individual data plans revealed that increasing incentives from 3% to 7% more than doubles the cost for operators, yet the corresponding traffic reduction does not scale proportionately with the increased cost. Therefore, it is essential to determine the appropriate incentive levels based on the targeted traffic reduction goals.

Future research should consider the varying degrees of individual incentives and

explore ways to tailor these incentives more effectively. Evaluating the economic value of social incentives could help reduce the monetary burden on operators while maximizing traffic reduction. Addressing the challenges of ensuring data security and user privacy in mobile caching networks remains crucial for broader adoption. Examining the long-term impacts of mobile caching on network performance and user behavior will be vital in refining and optimizing this approach for future applications. Finally, developing strategies to quantify and optimize the trade-off between incentive costs and traffic reduction benefits will be essential for the practical implementation of mobile caching solutions.

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