http://dx.doi.org/10.14236/ewic/BCSHCI2024.23

Evaluating a Mobile Game for Urban Exploration Utilising Mobile Edge Computing (MEC)

Ioannis Doumanis
University of Central Lancashire
Preston, UK
idoumanis@uclan.ac.uk

Kostantinos Tsioutas
Athens University of Economics and Business
Athens, Greece
ktsioutas@aueb.gr

Mobile gaming designed for urban exploration can quickly change how people interact with their city and others. These games help people explore and learn about their city while engaging and interacting with others in a fun and enjoyable way. However, the players' perceived quality of such games depends on various human, system and contextual factors. This paper presents the results of an empirical evaluation of a mobile game that encourages people to explore Bristol, UK. The quality of player experience (QoE) in urban environments requires studying end-to-end system effects, including players' experiences and the quality of mobile service (QoS). To evaluate the players' QoE, we implemented two networking scenarios on Bristol's smart city network: traditional IP and a Mobile Edge Computing (MEC) scenario using POINT, a content-centric network platform. The MEC-based mobile game offers better interaction latency than the IP version. We evaluated the impact of each scenario on the player's perceived Quality of Experience (QoE) and usability of the game in two field experiments. The results show that aspects of the players' QoE were significantly better with the MEC-based mobile game than with the IP version. However, players rated the usability of the two versions similarly. Behavioural analytics data indicate that the improved QoE of the MEC-based version resulted in a higher volume of video content production and recordings. Additionally, we found the time of day influenced the players' QoE, impacting the MEC version more than the IP version. Future work will focus on improving the game's usability to fully utilise MEC's advantages.

Mobile Edge Computing, QoE, QoS, usability, scavenger hunt game, empirical evaluation

1. INTRODUCTION

The evolution of mobile computing has been phenomenal in recent years. The significant increase in hardware power and bandwidth provided by the latest generation of mobile networks (5G) has enabled the development of many games, including the global phenomenon Pokemon GO[1]. According to a recent study (Futureplc 2024), adults spend 1 hour and 24 minutes daily playing games on their phones. This paper focuses on games explicitly designed to explore urban spaces (Tabi and Ikeda 2023) (Sánchez de Francisco, Díaz et al. 2023). These games encourage people to explore a city and take new routes, which for residents may include routes outside their daily routines and, for visitors, custom-made routes that match their interests.

The player's acceptance of smart city games depends on at least three factors: (a) how players perceive the quality of experience (QoE) (Möller and Raake 2014) and the usability of the game; (b) the appropriateness of the game to the user's situation and context and; (c) the Quality of Service (QoS) provided by the underlying service and network infrastructure. In our work under the EU-funded H2020 POINT project (Trossen, Reed et al. 2015), we investigated these factors by evaluating how players perceived the Quality of Experience (QoE) of a mobile game designed for urban exploration in Bristol, UK.

We developed a fully functional prototype of this game named BIO for Android platforms. After an internal review with internal stakeholders, we refined the game requirements and improved its design. The game invites players to solve various challenges in some of the most iconic locations of the city of Bristol, making it appealing to both residents and visitors. Our study assessed how players perceived the QoE, usability, and Quality of Service (QoS) using the state-of-the-art network infrastructure in Bristol, known as Bristol-is-Open (BIO).

Bristol is Open (BIO) is a collaborative project between the University of Bristol and the Bristol City

[1] https://pokemongolive.com/

Council in the 'Internet of Things' (IoT) domain. It aims to create one of the first programmable city regions in the UK, featuring a digital infrastructure that includes optical fibre, a mesh network bouncing from lamppost to lamppost, wireless connectivity, and more. This infrastructure is controlled by software, thus creating a software-defined network (SDN) (Serag, Abdalzaher et al. 2024), which is adaptable to use by various projects.

While the network operates on traditional IP, some access points (AP) have been enhanced with POINT technology, following a Mobile Edge Computing (MEC) architecture (Hu, Patel et al. 2015). We expected the MEC scenario would offer better interaction latency (Shi 2011) and smoother game delivery compared to the traditional IP set-up, thus positively affecting the user's perceived QoE and the game's usability. To validate these hypotheses, we conducted two studies: (1) a controlled experiment with a selected group of players 2) an open study offering the game on the Android marketplace for residents and visitors of Bristol.

The paper presents the design of each study, the data collection methods for QoE and QoS, and the significant findings. The remaining sections are organised as follows: Section 2 overviews the BIO game. Section 3 discusses the Mobile Edge Computing (MEC) set-up using POINT technology; Section 4 presents the empirical evaluation of the game, including the internal stakeholder review and the field studies in Bristol. Section 5 presents the results of the empirical evaluations. The paper concludes in section 6.

2. THE BIO GAME

BIO is a multiplayer scavenger hunt game supporting a maximum of three players at any time. The game is a hybrid mobile application designed to run on smartphones with Android OS. This means that the game is a web application within a native wrapper that relies on network connectivity for gameplay. Consequently, it requires few hardware resources to run on a mobile device, making the game accessible to many smartphone devices and potential players. The game follows a "discover a word" theme where players must uncover a six-letter word by visiting six locations in Bristol. To keep the game duration within reasonable limits, each player must only visit two Bristol locations assigned randomly by a group leader. We carefully chose each location close to BIO's network access points, such as a lamppost.

The game shows the locations each player must visit on a Google map (Figure 1). All locations are easily accessible, ensuring players do not get lost. However, if a player gets lost, they can call a provided mobile number for directions. Once a player arrives at a location, BIO automatically authorises them on the network and pushes a relevant game challenge to the player.

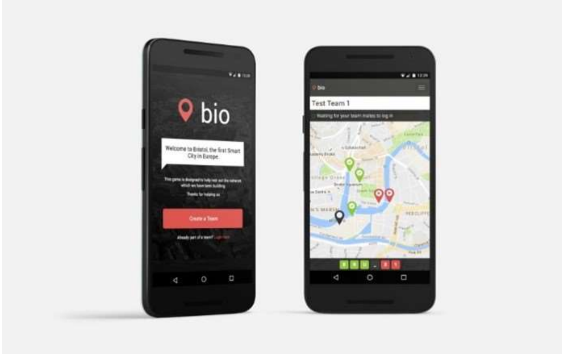

Figure 1: *The BIO Game*

A challenge can be a puzzle or a combination lock that players must solve to discover the missing letter. Most challenges require players to explore their surroundings. For example, a camera challenge requires players to find a commercial logo on a nearby building and point their device's camera to reveal the missing letter. When they do this correctly, a letter of the logo flashes, indicating success.

After discovering a letter, players must record a short video to notify their teammates and upload it to the game. The game automatically shares the video with the rest of the team. Once all players confirmed they had watched a video, the letter appeared at the bottom of their screens. When all players have discovered the word's letters, the game ends, and the completion time is recorded on a leaderboard.

3. THE MEC SCENARIO USING POINT

The POINT project (Trossen, Reed et al. 2015) explores whether IP-based applications can operate more efficiently on an IP network supported by an Information-Centric Networking (ICN) core. The project developed a commercially viable platform (POINT) which offers three distinct benefits over traditional IP networks (Doumanis, Phinikarides et al. 2018).

(i) **HTTP coincidental multicast:** A single HTTP response from the server can serve multiple users of the same service, enhancing efficiency.

(ii) **Increased network resilience:** POINT provides almost instantaneous rerouting during network failures, maintaining uninterrupted service.

(iii) **Surrogate servers:** While not native to POINT, these virtual servers are authorised copies of a physical server and can be created by an operator to meet rising demands for a particular service.

In the BIO context, we demonstrated *multicast* and *surrogacy*. Figure 2 illustrates the scenario we implemented in BIO. The logical POINT topology includes four hardware switches deployed in the city and Wi-Fi access points (APs) in lamp posts inter-connected via fibre. These APs, placed in cabinets next to the lamp posts, have computational resources to run POINT software. Communication between all APs and the server at the bottom right is achieved using the POINT platform. Each network access point has a co-located surrogate, providing an authorised copy of the central server.

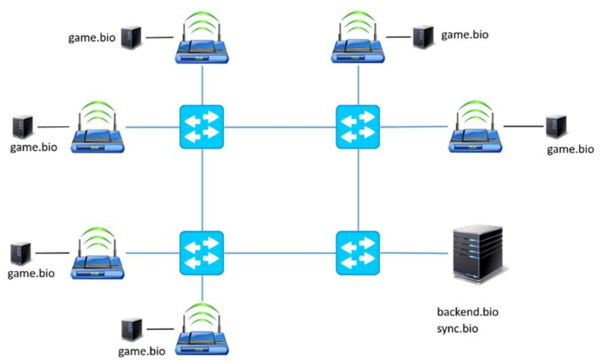

***Figure 2:** Logical topology of Bristol Is Open*

When the game notifies all users of new video content, all surrogates receive the content via multicast and serve it directly to the users without utilising any resources in the backbone network.

4. EMPIRICAL EVALUATION

4.1 Internal stakeholder review

We reviewed the BIO game with internal stakeholders in the laboratory. The goal was to assess the game's performance using a POINT-enabled network and resolve any remaining issues. We focused on the following aspects: (1) Game Caching and Synchronisation, addressing issues with data caching and synchronisation between players; (2) Usability, identifying issues that might prevent players from completing the game with completeness (effectiveness), little effort (efficiency) and satisfaction. (3) Video Quality and Playback, examining issues players might experience with video content. (4) Gameplay, evaluating how the game is played. (5) Research Instruments, integrating the research instruments for the study. A team of three experts completed the same challenges in the lab that real players would face in the field. A researcher moderated the session and asked questions about each player's experiences at the end. The session uncovered twenty-four issues across all five categories and added eight more based on observations. We converted the final list of thirty-two issues into requirements for the next design iteration of the game. To meet the project budget and time constraints, we also labelled each requirement as "Must" (Essential), "Should" (Desirable) and "Might" (It would be good to have but not a priority). Below, we present the design of two field experiments that took place in the city of Bristol, UK. At the beginning of each study, participants provided informed consent, and the game automatically assigned them to either the IP or MEC-based versions.

4.2 BIO Closed Trials

This study aimed to evaluate the impact of manipulating the type of game (IP-version vs. MEC-based version) on the user's perceived QoE and usability. We conducted the closed trials with 30 players, each playing the game in groups of three. The participants included visitors and residents of the city of Bristol, such as students from Bristol University.

To evaluate the players' QoE, we considered end-to-end system effects. We measured how players perceived their experience, performance and usability (ease of use) of the game. Additionally, we recorded the quality of service (QoS) metrics of the network between the player and the game server. Considering QoS was necessary as any variation in latency could negatively impact the players' QoE and usability.

For subjective measures, we asked players to complete two electronic questionnaires. The first questionnaire assessed QoE with the BIO game. Since BIO's network performance varied from location to location, we also expected the players' QoE to vary. Therefore, we asked players to complete the QoE questionnaire once per location. The QoE questionnaire, adapted from the Cloud Gaming questionnaire (Möller, Pommer et al. 2017), includes six items designed to evaluate various aspects of the players' QoE with the BIO game (e.g., video quality, audio quality and input sensitivity). The second questionnaire assessed the usability of the game using the SUS questionnaire (Brooke 2013), which includes ten items measuring the player's satisfaction (e.g., ease-of-use and efficiency).

For objective measures, we captured behavioural data during gameplay (e.g., GUI elements tapped, scrolling) and detailed performance data per location (e.g., how many players completed a challenge and how many abandoned a challenge). We also recorded HTTP requests (unicasts) and HTTP response gain (multicast) in time-stamped log files on POINT. The number of HTTP requests from the game impacts page load time and, hence, the players' QoE. The multicast gain events are the ratio of HTTP responses usually sent to HTTP responses sent due to coincidental multicast per time interval.

4.3 BIO Open Trial

This study aimed to evaluate the performance of the BIO game in an open environment. We made the game available on the Android marketplace and heavily marketed it to attract potential players. Six teams of three players (in total, 18 players) participated in the open trials. We recorded various aspects of the players' behaviour (e.g., engagement, geographical insights, collaborative behaviour) and evaluated their QoE. We designed a new questionnaire that assessed video and audio quality and player performance at each location.

5. RESULTS AND DISCUSSION

5.1 BIO Closed Trials

Regarding perceived QoE, ANOVA comparisons between teams and game types did not show any statistically significant differences ($p < 0.05$), indicating that players perceived MEC and IP versions of the game similarly. Similarly, we found no differences between game versions and teams regarding how players perceived its usability. Players rated the usability of both versions below average (SUS score = 68%). A probable reason for this low rating is the absence of a video notification system.

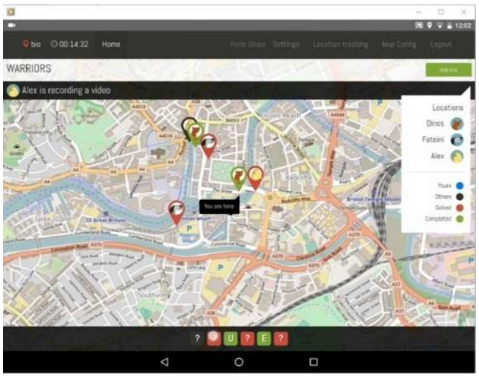

Figure 3: *A player waiting for two videos.*

As the game did not inform players when the next video would arrive, we observed that most players exhibited "rage taps," where players rapidly and repeatedly tap on the UI, unable to achieve their goal. For example, in Figure 3, a player saw that a teammate had completed two challenges but had not received the videos. They thought they could retrieve the two videos from the network by repeatedly tapping.

We investigated the lack of QoE impact in POINTs QoS data by computing the frequency of standard HTTP requests and HTTP response gain over time. Figure 4 shows that the green line (multicast gains) is more consistent and occurs at a higher frequency than the blue line (HTTP requests). This indicates that many of the game's HTTP requests were handled through multicast, reducing interaction latency. Since multicast can simultaneously handle multiple HTTP requests, the network does not need to process each HTTP request individually, reducing interaction latency.

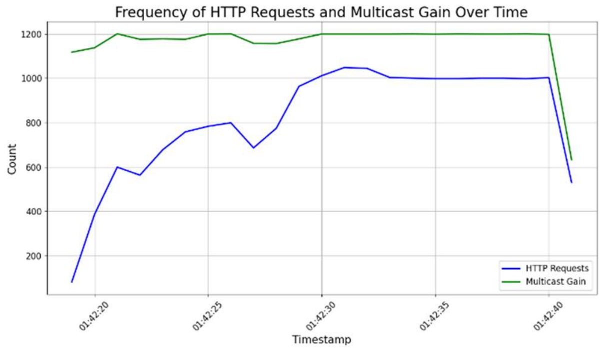

Figure 4: *Multicast Gain in the closed trials.*

Hence, despite the improved interaction latency, the MEC version of the game did not provide a better QoE than the IP version. It also did not positively impact the usability of the game. The trials uncovered additional usability problems that we had to address before the BIO game could benefit from the improved interaction latency provided by the POINT platform. Additionally, BIO's conventional IP network configuration ensured reliable performance (20ms delay and 30Mbps throughput at the time of the trial), making it more challenging to measure the effect of POINT (MEC version) on the perceived QoE of players.

5.2 BIO Open Trials

After completing the BIO Open trials, we fixed backend bugs in the game (e.g., connectivity issues), but we did not improve the UI due to time and budget constraints. As a result, players rated the usability of the game below average (SUS score = 62%). In terms of perceived QoE, Welch's t-test comparisons for game type showed the following significant differences (Table 1):

For Question 2 *("Please select any impairments you noticed in the video and/or audio")*, there was a significant difference between IP ($M = 4.68$, $SD = 0.95$) and MEC ($M = 6.00$, $SD = 1.29$) $t(33) = -3.58$, $p = .0011$. For Question 3 *("Did you notice any buffering in the video you just watched?")*, the t-test results showed a significant difference between IP ($M = 1.79$, $SD = 1.58$) and MEC ($M = 6.64$, $SD = 1.34$); $t(25.31) = -8.79$, $p < .001$.

Table 1: *Average scores for Q.2 and Q.3*

	Question 2	St.dev	Question 3	St.dev
IP	*4.68*	*0.95*	*1.79*	*1.58*
MEC	*6.00*	*1.29*	*6.64*	*1.34*

Table 1 shows how players rated two questionnaire items. They thought that MEC videos rarely buffered compared to IP videos. Although they noticed visual impairments with MEC videos (blurriness or stuttering), they also reported more severe problems with IP videos (e.g., dropped frames or block artefacts). The analysis of the player's behavioural data (Table 2) shows that players using the MEC version produced more video content at a greater frequency than players with the IP version.

Table 2: *Behavioural Data*

	Volume of Content (MB.)	Number of Recordings
IP	*76.14*	*16*
MEC	*90.73*	*22*

As players experienced less buffering with the MEC version of the game, they could better focus on creating video content and interacting with other players than the IP version. We also found a correlation between time of day and video size for both game types (IP and MEC).

The Pearson correlation coefficient for IP showed a negative relationship (r=-0.150) between video size and time of day. This means that players tend to record smaller videos later in the day, but the relationship is weak, suggesting that other significant factors influence the content volume produced.

For MEC, the correlation between time of day and video size showed a stronger negative relationship (r=-0.412), indicating that players recorded smaller videos later in the day, and the relationship is strong.

These correlations explain the ratings of players in Question 2. Players with the MEC version might have experienced poor lighting conditions later in the day, resulting in darker videos with noticeable blurriness or stuttering. The weaker correlation for the IP version suggests that while lighting conditions had some impact, it was less significant. For IP players, buffering was likely the most critical factor determining their video recording behaviour.

6. CONCLUSIONS

In this paper, we outlined a mobile game (BIO) designed to explore smart cities. We created the BIO game to enable people to discover the city of Bristol, UK. It is a hybrid Android application that requires access to Bristol's city network (Bristol is Open (BIO)) for gameplay. The BIO network runs on traditional IP, but some of its access points have been enabled with POINT technology. This networking delivery mechanism follows a Mobile Edge Computing (MEC) architecture, allowing the required game computation to occur at the network's edges and closer to the user. This approach offers the benefits of reduced interaction latency and smoother delivery. We conducted a review of an early prototype using internal stakeholders. The findings from the review helped us iterate and improve the game's design to maximise the player's experience. Additionally, we evaluated the players' perceived QoE and game usability in two field trials.

In the closed trials, players perceived QoE was similar across the IP and MEC versions of the game. Although the QoS data showed significant interaction latency improvements for the MEC version, players did not perceive any differences between IP and MEC. Initially, we thought the low usability of the game and the high performance of BIO's conventional IP network were the possible reasons. However, due to budget and time constraints, we did not run another design iteration for the game. We improved the network connectivity of the prototype and evaluated only the perceived QoE of players of a core game mechanic (video). We found that players with the MEC version perceived videos as rarely buffering, while they thought videos buffered more with the IP version. As players did not experience technical interruptions, they were more engaged in playing the game with the MEC version than the IP version. Buffering was likely the most critical factor influencing the recording behaviour of players with the IP version, whereas lighting conditions might have influenced players with the MEC version.

After completing the POINT project, we plan to improve the game's usability and release an updated version in the Android marketplace. We believe the improved usability will result in improved QoE (evaluated as a holistic measure and not just on video) for all players.

7. ACKNOWLEDGEMENTS

The research that led to this paper was supported in part by the European Commission under the Contract H2020 ICT project 6439.

8. REFERENCES

Brooke, J. (2013). "SUS: a retrospective." J. Usability Studies **8**(2): 29-40.

Doumanis, I., A. Phinikarides, G. Xylomenos, S. Porter and M. Georgiades (2018). "Improving video QoE with IP over ICN." International Journal of Network Management **30**: e2057.

Futureplc. (2024). "Over Two-thirds of US Adults Increase Time Spent Gaming." 2024, from https://www.globenewswire.com/news-release/2022/02/24/2391544/0/en/Over-Two-thirds-of-U-S-Adults-Increase-Time-Spent-Gaming.html.

Hu, Y. C., M. Patel, D. Sabella, N. Sprecher and V. Young (2015). "Mobile edge computing—A key technology towards 5G." ETSI white paper **11**(11): 1-16.

Möller, S., D. Pommer, J. Beyer and J. Rake-Revelant (2017). Factors Influencing Gaming QoE : Lessons Learned from the Evaluation of Cloud Gaming Services.

Möller, S. and A. Raake (2014). Quality of experience: advanced concepts, applications and methods, Springer.

Sánchez de Francisco, M., P. Díaz, T. Onorati and I. Aedo (2023). "Connecting citizens with urban environments through an augmented reality pervasive game." Multimedia Tools and Applications **82**(9): 12939-12955.

Serag, R. H., M. S. Abdalzaher, H. A. E. A. Elsayed, M. Sobh, M. Krichen and M. M. Salim (2024). "Machine-Learning-Based Traffic Classification in Software-Defined Networks." Electronics **13**(6): 1108.

Shi, S. (2011). Reduce latency: The key to successful interactive remote rendering systems. 2011 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops).

Tabi, S. and Y. Ikeda (2023). "Location Hunting Game: Developing an Application to Promote Gameful Hybrid Machi-aruki Town Exploration." Urban Science **7**(4): 126.

Trossen, D., M. J. Reed, J. Riihijärvi, M. Georgiades, N. Fotiou and G. Xylomenos (2015). IP over ICN - The better IP? 2015 European Conference on Networks and Communications (EuCNC).