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Passive profiling of mobile engaging behaviours via user-end application performance assessment☆

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ABSTRACT

Benefiting from the booming mobile industry, our daily connections have become instant and ubiquitous. In the meanwhile, user experience in mobile services becomes an important consideration for service providers to cultivate customers' loyalty, or for network operators to seek profit chances from existing infrastructure. To meet these requirements, we specify *engaging behaviours* to characterize the dynamics of user participation in mobile applications in real contexts. Leveraging a five-month collection of backbone traffic in an operational WiFi mesh network, we make comprehensive insights on the variation of engaging behaviours, as well as their non-linear and counter-intuitive interactions with user-perceived application performance. With the Hidden Markov Modelling of individual's engaging trajectory, two distinctive behavioural clusters are identified and investigated. These achievements will be contributed to the development of multiple pioneer R&D areas, such as mobile network simulation and user experience optimization.

1. Introduction

Mobile markets are driven to be explosive by the prosperity of portable devices and well-designed software applications. This trend also stimulates the research areas of ubiquitous computing [1] and human behaviour science [2] on behalf of convenient access of human generated mobile content. For example, the success of subscription and advertisement revenue models relies heavily upon the knowledge of user preference and participation learned from fragmented digital traces. In mobile world, an accurate profiling of user experience (UX) and engaging behaviour is of benefit to the resource optimization for service providers and even the hacking-perspective enhancement of user privacy protection.

User experience is a key aspect in designing human-centred technologies [1,3–5] and service models [6]. It usually focuses on the positive manner of user interactions with available resources, and particularly the phenomena associated with being captivated by technology or services. From end-users' view, a successful design of target products not only stimulates their interests to use it immediately, but also engage them with a solid endurability. However, the original designer begins to lose

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control with the way customers use the product, once it is shipped to the market in the deployment phase. The information of customer usage and experience becomes a precious source to enhance product features in the next iteration.

Since the birth of Internet, the collection of experience information about network applications has gained enthusiasm in multiple R&D areas. One of the modern and evolving concepts is *engagement*, once proposed by the Advertising Research Foundation (ASF) [7] and widely used in marketing policies. O'Brien initially borrowed the concept into web measurement and generalized it to cultivate user-technology interactions [3]. The framework is a participation-based model which characterizes different temporal stages (e.g., engagement and disengagement) when users are involving in an application. As a complementary view, a functionality-based model with multiple engagement dimensions (e.g., endurability) is discussed in [8] which connects theoretical notations with practical metrics.

Despite the generality of these two frameworks, they suffer from two main weaknesses when we evaluate mobile user engaging behaviours: the deficiency of contextual adaptation and a lack of quantitative correlative interpretation. In mobile networks, contextual factors impact user engaging behaviours in multiple facets (such as temporal effect [9], applications [2], geographic locations [10], and public events [11]), while the quantitative correlation interpretation sheds light on developing diagnostic and actionable policies for mobile user experience. The correlative interactions are also addressed in recent video community [12–14], and yet user behaviours in mobile networks have not gained comprehension in a large-scale and systematic manner. In this paper, we focus on the profiling and modelling of user participating behaviours in mobile services, especially the interactions with user-perceived application performance in varying contexts.

For the assessment of user engaging properties and perceived application performance, we have two board alternative methods: subjective and objective [8]. The former recording user experience via interviews or questionnaires [3], represents real user experience but suffers from drawbacks such as lab-setting bias and individual cognitive prejudice (a.k.a. "halo effect" [15]). The latter based on passively collected metrics from communication data or management logs, suppresses the drawbacks and branches out conveniently into large-scale characterization. In this sense, we perform the passive measurement in our studies.

Although passive measurements of mobile traffic have been conducted in previous literature [16–18], they mostly address protocol and traffic properties, rather than responsive user behaviour consequences. For example, the same user under similar environment is observed having distinctive behavioural patterns against the degradation of network performance (Section 4.4). Furthermore, measuring protocol performance solo is far away from user experience, because low-level metrics (e.g., flow byte rate) explicate the efficiency of data transmission experienced by networks rather than by users [18]. In a different manner, we develop a set of objective user-centred metrics of user engaging behaviours and application performance. The profiling substance comes from an augmented behavioural model of mobile traffic, which gains a higher accuracy than existing models as for explicit distinction of engaging activities from network perspective. With this model, we make three contributions from following perspectives:

- Perform a characterization of mobile traffic and engaging behaviours from end-user's view. The proposed concurrence index equipped by the model is more powerful to capture delicate difference of user-perceived application performance than previous volume-based metrics (Section 3.3).
- Profile the behavioural dynamics of user participation in mobile usage and its interaction with user-perceived application performance. We observe high skewness of engaging session lengths and large diversity of user engagement on differing device platforms. The contextual factors also put significant impacts on the interaction (Section 3.4).
- Perform a unique modelling of individual engaging trajectories and a model-based clustering to explore user behavioural patterns. We find that user engaging behaviour is primarily governed by a small portion of latent states, and the behavioural patterns regarding principle engaging states illustrate distinctive properties in discovered user clusters (Section 3.5).

The remaining parts are structured as follows. Section 2 reviews previous literature on related topics. Section 3 describes the global methodology to analyse and model mobile engaging behaviours passively. Section 4 shows the experimental results, and we finalize the paper with a discussion on potential applications and limitations in Section 5.

2. Related work

A brief literature review is made on the general user engagement frameworks and mobile traffic measurement. Relative achievements are classified into three main categories:

General frameworks of user engagement: Several conceptual frameworks have been proposed on user engagement in different domains, including the participation-based [3] and functionality-based [8] models for technologies. Authors in [3] decompose user engagement into four distinct stages according their occurrence order (i.e., point of engagement, period of sustained engagement, disengagement, re-engagement), and discuss a wide range of attributes attached to each stage. Researchers in [8] address the functionality of engagement properties as well as their measurement in front-end web technology. Beyond technology domain, considering customer engagement in business models [6] gives assistance to understanding customer-brand value exchange and improving customer loyalties.

Measurement of user engagement: Subjective methods evaluate user experience directly via, e.g., questionnaires [13] or MOS metric [19], while objective methods suppress the subjectivity bias of the former and are suitable for quantitative analysis. In related domains, a batch of objective analytics have been proposed to study user engagement in computer