Realising Anticipatory Networks through Human Aware Networking (HAN)

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***Abstract*—Telecommunication networks currently follow the reactive approach; that is, network conditions change based on current behaviour of users and state of network resources. However, network efficiency and resource optimization can increase manifold, if the networks had the capability to anticipate behaviour of users and their network utilization. This vision, thus far, has remained largely theoretical. However, considering research in ubiquitous computing and machine learning with respect to: i) understanding user behaviour patterns, ii) establishment of user behaviour models and iii) anticipation of future user behaviour based on the established behaviour model, the vision of anticipatory networks comes closer to reality. The realisation of this vision will be a result of amalgamating human behaviour research in ubiquitous computing that through anticipation of user behaviour will be a key element in network resources optimisation. We call this vision, Human-Aware networking (HAN).**

Keywords—human aware networking; network performance; network optimisation; user behaviour analysis; user behaviour modelling

I. Introduction

Human-aware networking is an interdisciplinary research area that lies in the intersection between Ubiquitous computing [1] and Network optimisation. This research area seeks to improve operation quality and efficiency of networks by incorporating a key element in the process: anticipation of user behaviour. Anticipating user behaviour and predicting future user actions, has the potential to establish highly optimised networks that are able to respond to users' needs whilst maintaining actual Quality of Service (QoS) and perceived Quality of Experience (QoE).

One strand of ubiquitous computing research has focused on understanding human behaviour through the use of unobtrusive monitoring technologies, typically mobile phones. For example, research work in [2] has investigated use of mobile phones in monitoring social interactions of the user. This was done based on non-verbal human behaviour clues, extracted from the sensor data captured through mobile phones, namely distance based on WiFi sensor and mutual orientation based on the phone's compass sensor. In addition, authors managed not only to detect social interaction behaviour, but also to classify it, whether the social interaction was formal or informal. In addition, mobile phones were also used to understand behaviour of patients with bipolar disorder and predict their transitions between the episodes [13], using two sensing modalities: physical activity levels extracted from the phone's accelerometers and mobility. Smartphone apps usage, which could have a direct impact on the network performance, has been studied from the point of view of users' mood, demonstrating correlation between the mood of the users and specific categories of apps used on the mobile phone [14].

Thus far, the knowledge about human behaviour has been generally applied in scenarios for the benefit of the users. In particular, advances in context awareness in the domain of ubiquitous computing has allowed to better model and interpret the state of the users and their environment, and to allow systems to react accordingly to contextual changes for improving different aspects of users life. The number of applications domain of ubicomp impacted by context awareness research is multiple, ranging from assisted living to entertainment, smart transportation and healthcare amongst others. A common denominator on such applications is that the availability of network services in previous ubicomp research was usually given for granted and the performance of systems was not always tested in real-life conditions regarding available connectivity [3].

This is because the current modus operandi of telecommunications networks follows the reactive approach. That is, networks react on the current performance metrics and demand of network resources, while anticipation of users' behaviour and consequently, future demand is not widely taken into consideration. One explanation for this, may be the fact that predicting human behaviour requires unobtrusive monitoring of current user behaviour, which has been possible only in recent years with the advancement and miniaturisation of technology, especially technology incorporated in mobile phones. As described above, mobile phones provide a wealth of information about the behaviour of the users, including their mobility patterns, physical activity levels, social activity behaviour through a combination of calls/sms and social apps.

This amount of information allows establishment of user behaviour models, which can then be used to anticipate future user actions and extract aspects that are relevant to network optimisation. This in turn allows establishment of human-aware networks that through anticipation of user actions gain the capability to optimise network resources with respect to QoS and QoE.

Such radical changes to network design have led network operators and vendors to consider fundamental changes in the design of the future fifth generation (5G) cellular networks [18]. The industry perception towards the concept of mobile performance is evolving, and so are the associated performance metrics. Today, 4G network performance is evaluated based on “hard” metrics, including peak data rates, coverage, and spectral efficiency. The 5G networks are expected to expand the performance metrics centered on the user’s quality of experience (QoE), both in a qualitative and quantitative sense, including factors such as ease of connectivity with nearby devices, improved energy efficiency etc. Such user-centric and context-aware notion will permit operators to deliver personalized content and assistance services. However, the 5G architecture and the network elements should incorporate new ways to deliver this level of personalization.

II. Related work

To the authors knowledge there is not previous work reported in the literature on utilizing user activity and behavior analysis detected from mobile devices for maximizing QoE in networking scenarios. However there is previous work in the fields of ubicomp and networking that if related together, may be used as foundations for setting up a path of convergence between these two research disciplines for developing the HAN paradigm. HAN may benefit from the experience of 1) ubicomp research on acquiring needs, contexts and identified behaviors from users domain and 2) networking research for estimating optimum connectivity parameters from networked applications domain.

A. Ubicomp Assets for Networking

Advances in ubicomp research allow to perform human activity and context recognition through wearable and mobile devices with reasonably high accuracy defined under non-ambiguous and measurable performance criteria [4]. Several application domains such as wellbeing, fitness, assisted living, smart transportation, logistics, healthcare, energy saving, self-management, entertainment and marketing amongst others have found a benefit on the use of context and activity recognition through the usage of mobile devices [5]. Moreover these researches focus mainly on impacting aspects of daily living of users and still haven’t exploited their potential to contribute to networking domain. In addition, research on automatic mobile monitoring has achieved to estimate not only objective data representing specific activities such as walking, running, sleeping, etc. but to provide the basis for understanding more sophisticated human behaviours from automatically captured behavioural cues (like in honest signals research) such as sociability, mood, and human intentions [6]. In particular referring to estimation of human intentions, the prediction of activities and behaviours using mobile phones sensors in past ubicomp research has demonstrated to be feasible [7].

Other recent work in ubicomp community relevant for HAN paradigm development consists in predicting mobile applications usage accordingly to previous behaviour patterns and users intentions [8]. On their research the main motivation was to understand and predict applications usage in different locations and contexts for providing users with simplified access through adaptive user interfaces in the mobile phone screen depending on most frequently used applications. Other related research, defined new applications usage models for producing robust app predictions for enabling in one hand significant smartphone system optimizations at the interface level and in the other to proposed possible future developments on pre-loading apps when potentially needed for giving a perception of being virtually instantaneous and to cache network content potentially providing the appearance to the user of much higher network speeds [9].

B. Networking Related Research

Ongoing research on Applications Aware Networking (AAN) is related to HAN in the sense that it focuses on defining the network resources based on customer demand. In these cases, application awareness is related to the different tools that service providers use to optimize network resources accordingly to the required performance of overlay applications in terms of bandwidth, delay and jitter among others. In AAN the focus is on understanding the requirements from the different applications in order to define resources allocation through a Software-Defined-Networking (SDN) approach. An example of this is the provisioning of prioritized Service Levels Agreements (SLAs) depending on the requirements of different types of applications. Differently to HAN, in AAN, the focus is on applications while the user behavior and intentions are not considered to establish possible network consumption demands.

Other research considers content consumption patterns of users and connected objects that are located in proximity in order to identify frequently used content and position it in nodes nearby [10]. This is done by establishing relational metrics among objects in the real world (e.g. people, locations, things) and the content itself to establish closeness relationships and similarity patterns on content consumption relating users through a social-distance criteria [11]. With this approach the intention is to reduce traffic congestion by moving and storing the frequently used content by a series of users in nearby nodes to provide better content delivery.

Recent approaches are focusing on the concept and theoretical foundation of Anticipatory Networks [12] to exploit network predictability and adaptability to upcoming events in a way to anticipate requirements to improve operation quality and efficiency. This approach is well in-line with potential future scenarios enabled by 5G technologies and the upcoming next wave of the digital society.

III. Insights and Potential Challenges

One of the grand challenges in realizing Human-aware networking will require paradigm shift from current reactive networks to proactive and anticipatory networks with the human behaviour analysis as the key input to anticipatory networks. Real-time human behaviour analysis plays an important role in network performance and when brought down to networking, will call for a foundational, human-aware layer, a rethinking of networks and networked services, which need to embed a thorough quantitative understanding of the human behaviour, as well as modelling and design methodologies for capturing and exploiting such human-network interaction. By incorporating such a proactive user-centric paradigm to 5G network architecture will allow the network nodes (i.e., base stations and handhelds/smartphones) to exploit the users' context information, anticipate the users' demands and leverage their predictive abilities to achieve significant resource savings to guarantee the perceived quality-of-service (QoS) requirements and cost/energy expenditures [16]. As a result of such human-aware network layer incorporated into the 5G paradigm, the network and its elements can collectively track, learn and build users' demand profiles to predict/anticipate future requests, leveraging the user requests (henceforth the user behaviour) and the vast amount of available data. Leveraging the predictive capabilities, users are scheduled in a more efficient manner and resources maybe pre-allocated more intelligently, by anticipating the peak-hour demands during the off-peak times.

By exploiting the statistical traffic patterns and users' context information, the human-aware network paradigm allows to better predict when users contents are requested with the appropriate amount of resources needed. The novel design paradigms that allow proactive caching of information close to the network edge can leverage such user-awareness in an efficient manner, whereby the network is aware of the locations where the contents interested for the user are pre-cached. Furthermore, such user-awareness will improve resource efficiency in terms of managing the mobility in the network, which is a major bottleneck in 4G networks, and at the same time, will permit the dense 5G networks to save enormous amounts of energy by reducing the amount of signalling information, and backhaul traffic, especially by predicting the user behaviour and context/content requirements.

However, 5G networks are predicted to move from the current human-centric communication scenarios to largely machine-oriented communication scenarios, leading to the coexistence of human-centric and machine-type applications which will impose very diverse requirements on future 5G network deployments [15]. Such new scenarios, e.g. mission-critical control applications, will create far more stringent latency and most importantly, flexibility and reliability requirements on future mobile and wireless communication systems [17]. Such diversity in the connected devices calls for specific attention to the way in which the anticipatory network paradigm is designed which can incorporate the diverse user requirements and provide the ultra-reliability and tactile features that are expected by the future 5G scenarios. A great degree of simplification can be achieved by anticipating the user needs in a fine-grained manner, categorized by the devices'/users' expectations, and matching it with the network state, which will permit the operators to provision resources in a transparent and scalable manner for the wide variety of services without saturating the network. Furthermore, the network operators can indulge into novel means of management of the services, by incorporating dynamic metrics linked to the anticipatory behaviour, assessing user/machine behaviour/expectations and at the same time, measuring the network state in a proactive and time-bound manner.

There are three challenges that emerge, tightly intertwined: First, user interests should be matched with network-related aspects (cost, performance, quality of the expected access/delivery conditions, predictions on resource availability, etc). Since network load is ultimately determined by the free choice of the user among alternatives, a thorough understanding is required on how network feedbacks should be devised and presented, and how humans react to network feedbacks in taking alternative decisions. As such, methodologies and insights adapted from human sciences, as well as cognitive models of decision-making, become now essential and integral aspects in networking.

Second, human behaviour becomes a novel key instrument for controlling network performance and providing improved quality of experience and better end user services. The exploitation of the human dimension in the network operation indeed calls for solutions able to discover, predict and rank, best fit opportunistically available resources and services, along with new algorithms able to integrate human adaptability in the network operation, and means to devise the most effective and convenient feedbacks to the users. Third, the current telecommunication networks, in particular, the 4G mobile networks, are heavily network-centric and the resources scheduled for the users and the applications/services that are provisioned for the users and the user QoS are largely dimensioned by the network in a static manner. Inorder to incorporate the user behaviour, application-awareness and the dynamic network state in a consistent manner, the network elements, in particular, at the edges, need to be re-designed to tune to such changes, and the same time, there should be an architectural implication on the end-to-end scale, whereby the collective impact of the anticipatory changes to the network is efficiently managed. This calls for more integrated device-centric 5G architecture design and disruptive changes in the system level that collectively impacts the network nodes and elements.

The ability to change the network performance not only through usual routing, caching, or data replication means, but also through network-assisted human workload adaptation via tailored network feedbacks, calls for a rethinking of network optimization and traffic engineering approaches, either in terms of models and relevant formulations, as well as in terms of exploited methodologies, which should be made capable of capturing the human behavior. At the same time, a new research avenue consists in the network-aware rethinking of recommending and incentive/reward systems. We believe that the experience of previous work in ubicomp and networking can exploit their synergies to constitute the basis for the required research agenda leading to Human-Aware Networking, as a possible approach to address predictability of users needs and the consequent anticipation of network provisioning.

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