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Multi-criteria optimization of wireless connectivity over sparse networks

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ABSTRACT

Opportunistic networking is at the basis of cyber-physical Mobile Networks in Proximity (MNP), through its unique perspective over mobility and the incorporation of socio-inspired networking algorithms. However, results in the field are mostly theoretical, proven to account for stricter hit rate and latency requirements in specific environments. They generally assume that two devices being in proximity automatically see one-another, an assumption which might not stand under real-world conditions (Bluetooth assumes a peering session and close-proximity, WiFi Direct implementations are different between manufacturers, etc.).

Our previous studies in the area show that WiFi is still the most feasible media for opportunistic contacts. WiFi-enabled devices, with out-of-the-box networking capabilities, can connect in an ad-hoc opportunistic network, over wireless routers, and thus support a cyber-physical infrastructure for opportunistically spreading information.

In this article, we propose a machine learning algorithm that aims to increase the number of contacts between mobile nodes by using a smarter WiFi access point selection heuristic. The algorithm is based on properly balancing signal strength, latency, bandwidth, and, most importantly, the number of friends predicted to connect to the respective access point. We show through simulations based on real-life tracing data-sets that our proposed solution not only increases the likelihood of opportunistic contacts, but it also evenly distributes social subgraphs of users over wireless networks while improving the overall hit rate.

1. Introduction

Opportunistic networks (ONs) are a type of infrastructure-less mobile network, in which nodes are mobile devices carried around by humans and communicate with each other when in proximity via the *store-carry-and-forward* paradigm. When not in direct proximity, the source node opportunistically forwards the message through the nodes in its wireless range. These nodes carry the message either until the destination is met or the message expires.

Recently, there has been an increase in the interest in ONs, as they show great potential towards the realisation of Mobile Networking in Proximity (MNP) and cyber-physical systems alike[1]. This community-driven type of network offers a good platform for distributed context sharing. Given the always on-the-move nature of people, this type of network often faces many disconnections and variable delays, and can go from being sparsely connected, in secluded locations, to being densely connected, in public places, or in scenarios where an Internet connection might not even be available. This makes it difficult to properly route messages between the mobile nodes. In essence, MNPs represent spontaneous networks composed of mobile nodes that opportunistically connect in a peer-to-peer (P2P) manner when in proximity to one another[2]; as such, opportunistic networking clearly encompasses all concepts from MNP, as it combines the social nature of mobile nodes with techniques from mobile P2P[3].

Our previous studies have shown that opportunistic networks combined with social information, are more than suitable for generating and sharing large amounts of data [4,5], and even for distributed computing [6,7], while maintaining acceptable hit rates and latencies [8,9]. In [10], we showed that WiFi is the most feasible media for opportunistic networking; due to its higher wireless range and broader bandwidth, it is able to support more opportunistic contacts than Bluetooth, which, on the other hand, tends to isolate users into micro-communities. Furthermore, WiFi is fully-standardized and supported over all major mobile platforms, as opposed to near field communication

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(NFC) or WiFi Direct, which are not uniformly implemented by all modern mobile operating systems (OSs).

However, using WiFi as the media for opportunistic contacts, implies that the performance of ONs is dependent on the local infrastructure; nodes are discovered through multicast in the local wireless area network. Therefore, opportunistic contacts are established between nodes that are connected to the same wireless access point (AP). Currently, most mobile OSs only focus on connecting to APs that provide a more stable Internet connection and, for this reason, they only take simple metrics into account, such as choosing the best signal strength. However, such functionality is not relevant for ONs, which do not rely on the Internet for routing or forwarding messages, rather they make use of any available wireless connection between two mobile nodes in order to direct a message towards its destination. As such, we propose to design a WiFi AP selection algorithm that attempts to increase the number of opportunistic contacts between nodes that share social bonds; in our work, a social bond is considered to be a link in the social graph, namely a relationship between two nodes in an online social network [11]. By doing so, we believe that we are able to significantly increase the chances of messages reaching their destination, thus maximizing the hit rate and minimizing the latency of ONs. Moreover, we attempt to alleviate congestion, by distributing nodes grouped by social links towards the same wireless APs. The novelty of the solution stems from the decoupled nature of the algorithm: mobile nodes act independently of one another and, through exchanging messages during opportunistic contacts, they learn the behaviour of other nodes socially connected to them so that they connect to the same APs. This is achieved without any broadband Internet connections, thus being able to meet the low-latency requirements from MEC (Mobile Edge Computing).

The remainder of this article is organized as follows. Section 2 presents a comparison of existing algorithms. In Section 3 we propose a new algorithm for AP selection, with an extended focus on improving ONs. Section 4 details the implementation of the simulation platform; it also provides an in-depth performance analysis of our proposed solution in comparison with existing algorithms. Finally, Section 5 gives a summary of the article and of the obtained results.

2. Related work

As WiFi has become nearly ubiquitous, AP selection algorithms have been the main focus point of both the mobile computing research community, as well as of the mobile industry. Most modern mobile OSs use signal strength as the main criteria for choosing the most appropriate AP. According to the official support guide [12], iOS 8 selects target Basic Service Set Identifiers (BSSIDs) based on the difference in signal strength against the current BSSID's Received Signal Strength Indicator (RSSI). Furthermore, it selects target BSSIDs whose reported RSSI is $8dB$ or greater than the current BSSID's RSSI if the client is transmitting or receiving data, and $12dB$ for idle clients. Android is also focused on choosing the AP with best signal strength, but it is more customizable [13] by using a *wpa_supplicant* configuration file which allows choosing other network criteria, such as security policy. However, this behaviour is used by both OSs only when interacting with unknown APs. Whenever the mobile node is near a series of APs in which at least one of them is known, it uses its caching capabilities to connect to the last connected AP from that list.

Most existing algorithms for selecting APs aim to improve bandwidth allocation or maximize throughput for broadband connections. While these criteria should still be met by our solution, they are secondary objectives in ONs. This is due to the fact that the main purpose in such networks is to accurately route messages between devices without the necessity of an Internet connection. Therefore, the main criteria to improve is the number of meaningful connections between similar users. There are several attempts at improving bandwidth fairness, in which all nodes connecting to the same AP share the provided network resources in an equitable manner, either by probing [14], by introducing notions from game theory [15,16], or even by creating a system in which APs communicate between themselves in order to gain better understanding of the overall state of the system in order to apply a modified version of the max-flow algorithm [17]. As for improving network throughput, authors in [15] introduce an algorithm in which throughput is maximized by calculating regret for a selected connection as the difference in payoff between possible and actual AP choices, and improving the selection process based on learning historical values.

Tabrizi et al. [18] focus on maximizing Quality of Service (QoS) through a reinforcement learning algorithm which calculates a reward for each encountered AP based on probed throughput. Our solution improves on this approach, as we estimate the selection criteria by keeping detailed history and using the predictability of the average human schedule to our advantage in offering more accurate data, as opposed to probing for momentary data. Also based on the predictability of human mobility, Pang et al. [19] propose building a generalized system based on user-submitted reports which are used to predict future events.

Another interesting approach at solving the AP Selection problem is Virgil [20], a selection algorithm which aims to satisfy varied QoS constraints. On each discovered AP, Virgil quickly connects the mobile device to it, and runs a battery of simple tests, designed to probe the AP's availability for use. It uses reference servers and estimates bandwidth and round trip time (RTT) while also testing its open ports in order to calculate a score for each AP. The results are stored in a local database for future estimates. Although an interesting solution, Virgil represents a complex probing mechanism, which only allows logging for future predictions which can lead to improving the accuracy of the results. The main criteria it aims to improve is the average percent of actually finding a connectible AP. It manages to achieve results of 20 to 100% better than those obtained by the regular maximum signal strength approach. However, the authors highlight that the number of connectible APs found with a scan is low. Over 60% of all scans find less than 3 APs that are connectible. This strengthens the motivation for our solution which attempts to find the AP which maximizes our potential for social interactions in ONs.

Fukuda et al. [21] propose a decentralized solution for AP selection which attempts to solve the problem of imbalanced traffic load on APs. It consists of probing the available APs from a scan and using one of two selection algorithms: maximizing local throughput (MLT) or avoiding APs with larger packet error rates (AALP). However, the waiting time required for probing each AP, especially in the case of timeouts, is not viable when the user wants to connect to other nodes as quickly as possible. Our proposed solution uses local historical values to predict viable candidates, thus removing the need for probing and making a seamless transition between the current AP and the better choice.

As an overview, our solution provides a smart decision for choosing APs in order to increase the number of opportunistic contacts between peers that are socially connected. This is achieved through a machine learning algorithm that is able to record the behaviour of other nodes, thus enabling a decentralized AP selection decision. Moreover, the algorithm seamlessly complements existing algorithms implemented in mobile OSs by also balancing the signal strength, the available bandwidth and the connection latency. Our solution takes energy efficiency into account through removing the need for probing, and evenly distributing social subgraphs of users towards the same APs in order to reduce network congestion.

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