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WLAN-Opp: Ad-hoc-less opportunistic networking on smartphones

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ABSTRACT

Opportunistic networking enables many appealing applications including local social-networking, communication in emergency situations, and circumventing censorship. The increasing penetration of smartphones should, in theory, foster opportunistic networking. In practice, current candidate technologies for opportunistic networking, such as Wi-Fi ad-hoc, Bluetooth, and Wi-Fi Direct, are either not available on current smartphones, or require undesired user interaction to establish connectivity.

To overcome these shortcomings, we propose WLAN-Opp for smartphones. This IEEE 802.11-based technology leverages the tethering mode of smartphones, a feature originally used to share Internet access, which allows smartphones to become WLAN-based access points that provide networks for other smartphones operating as stations. The transitions between WLAN-Opp access point and station mode are randomized as a function of the number of other co-located networks and stations, and depend on duty cycling intervals. We optimize the probabilistic operations in a simulation study and provide a parametrized implementation of WLAN-Opp for out of the box smartphones. By replaying real contact traces in simulation, we find that WLAN-Opp can utilize up to 80% of the contact time while saving up to 90% of the energy Wi-Fi ad-hoc would consume. Finally, we demonstrate in a field trial with 34 users over 5 days that WLAN-Opp can provide a practical solution in a realistic setting.

1. Introduction

Ubiquitous network connectivity is often taken for granted in developed countries. Yet, natural disasters such as earthquakes or floods, which occur more often then commonly believed [5], hamper the performance of communication networks and, in worst case, may destroy network infrastructures. Another example of missing connectivity can be found in developing countries where high-bandwidth connectivity is not provided area-wide. Even if networks are available, authoritarian governments often censor communication by blocking access to information and online social networks (e.g., YouTube, Facebook, Twitter) [9] and can even cause an Internet and mobile phone outage [4].

Opportunistic networks provide an appealing technology to maintain delay-tolerant connectivity under such harsh conditions as well as offload existing infrastructure [8,17], or even support freedom of speech. In opportunistic networks [2,20], mobile wireless devices cooperate to distribute information over spontaneous wireless links whenever mobile devices encounter one another. The increasing penetration of smartphones and tablets favor

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the feasibility of such networks, however, there is a lack of enabling networking technologies for ad-hoc establishment of wireless links in today's smart mobile devices. Most of all, common smartphones do not support IEEE 802.11 WLAN ad-hoc [12], unless rooted or jail-broken. Communicating via Bluetooth is another option, but this option is limited in terms of communication range and bandwidth as well as human interaction-free discoverability. Although recent developments achieve wider ranges and better transfer rates through hybrid solutions, still WLAN-based networking provides at least 3–10 times wider ranges and 20 times higher rates. Wi-Fi Direct [27], the Wi-Fi Alliance's answer to Bluetooth suffers from cumbersome manual discovery and pairing procedures which in addition are very energy intensive [26].

With WLAN-Opp, we propose an approach to establish connectivity among modern smartphones based on basic WLAN infrastructure functionality, namely access points (APs) and its associated stations (STAs). WLAN-Opp uses the tethering mode of smartphones that allows the device to become an AP. This way, a communication infrastructure is established for co-located devices (devices in contact), which in turn can connect to the provided WLAN network as stations without requiring time-consuming pairing of devices or cumbersome user input on encounters. Further, the functions necessary for WLAN-Opp are provided by the API of common smartphones. These characteristics make WLAN-Opp a very practical opportunistic networking approach.

Conceptually, WLAN-Opp allows to adapt to various topologies of co-located devices by controlling periods of scanning and connectivity, and changing between AP and station mode. The flexibility in changing between AP and station mode allows to share the load of providing AP functionality and, thus to control resource consumption, in particular battery power. Yet, providing the necessary connectivity in a dynamic environment where mobile devices appear and disappear frequently is not straight forward. To solve this problem, WLAN-Opp introduces parametrized randomization of state changes as a core method.

We presented the concept of WLAN-Opp first in [25], where we provided a proof of concept based on simulation. In this paper, we extend our work by a detailed description of a more realistic and flexible WLAN-Opp state machine and a detailed investigation of its major parameters and their impact on *contact utilization*, i.e., the fraction of the time co-located devices can actually communicate via WLAN-Opp. Further we validate the simulated state machine by an implementation of WLAN-Opp on real devices. Overall, we make the following contributions:

- We introduce the details of WLAN-Opp including the state model, randomization, and parameters controlling the behavior of WLAN-Opp (Section 2). We investigate these parameters for varying amounts of co-located devices in a stationary setting using event-driven simulation. As a result of this study, we provide an appropriate configuration of WLAN-Opp for good contact utilization (Section 3).
- By exposing WLAN-Opp to a set of real mobility traces we demonstrate that the occurring contacts are well utilized by WLAN-Opp, i.e., up to 80%, while saving up tp 90% of the energy Wi-Fi ad-hoc would consume (Section 4).
- We implement WLAN-Opp on Android, the currently dominating mobile OS, and make it available as open-source. Using this implementation, we validate our approach by comparing simulation and real measurements and thus show that our simulation model accurately matches the behavior of real smartphones (Section 5).
- Finally, we present a field study lasting over five days with 34 participants and demonstrate the practicality of WLAN-Opp on real devices in an every-day setting. This experiment also shows the usefulness of an additional feature of WLAN-Opp, i.e., leveraging available open access points in the environment to save energy (Section 6).

2. WLAN-Opp

WLAN-Opp uses the WLAN access point feature of mobile phones to enable delay tolerant connectivity. Some devices change into access point mode (AP) and provide the wireless network, while other devices are in idle mode (IDLE) and scan for networks or are connected to a network as a station (STA). In STA mode, devices are still able to scan and discover additional networks. Fig. 1a shows the simplest WLAN-Opp network between one AP and one STA node.

2.1. Challenges

Establishing opportunistic connectivity between mobile devices in proximity is the primary goal of WLAN-Opp. Therefore, being aware of other nodes and coordinated AP mode provisioning are key factors to be considered by the opportunistic networking scheme, which faces the following challenges[1]:

- IDLE nodes can scan for networks to discover APs, but are unaware each other (Fig. 1b). A fraction of nodes may thus be in proximity but not (yet) connected.
- APs are unable to scan for networks and are thus unable to detect each other (Fig. 1c). APs are only aware of their STAs, i.e., nodes that are associated with them. Hence, they might miss opportunities to join other existing networks in proximity leading to partitioned networks (disjoint groups, cf. Fig. 1d).
- Finally, STAs associated with different APs are not aware of each other. This is the second cause for disjoint groups that are unable to communicate with each other (Fig. 1d).

[1] These challenges are mainly given by the smartphone's OS and solvable with access to the Wi-Fi driver. However, this would require rooting the device or installing a custom Android OS.