Battery Life of Mobile Peers with UMTS and WLAN in a Kademlia-based P2P Overlay

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Abstract—**We evaluate the battery life of mobile devices that act as full-fledged peer nodes in a Kademlia DHT based P2P overlay network. The motivation is to find out how long a mobile peer is able to function in a UMTS or WLAN access network, and how the different parameter settings affect this battery life; this is interesting as mobile access to P2P networks is expected to become common in the near future. The majority of the peers in an overlay are simulated on a server array, while the power measurements are conducted on actual mobile devices. The variable overlay parameters are the number of peers, resource lookup activity, and the level of churn. The chosen values of parameters represent a relatively high amount of activity. In UMTS the measured battery life is approximately 3 hours and in WLAN it is 5 to 10 (most often around 8) hours. We also provide power measurements on sending and receiving UDP packets in UMTS and WLAN, for approximating the power consumption of network protocols without protocol-specific measurements.**

Keywords-battery life; mobile peer-to-peer networking; protocol energy efficiency; structured overlay networks

I. INTRODUCTION

In order to enable peer-to-peer (P2P) networking in the mobile realm, it is important to study how long a battery-powered device is able to participate as a peer in an active overlay network, and what are the corresponding power consumption levels of the device. The information helps to understand 1) whether the P2P protocols are suitable for mobile use in their present form or do they need modifications; 2) how the different overlay parameters affect the battery life; 3) how large is the marginal of power available to the mobile device's other activities besides P2P participation; and 4) what kind of increase in battery life for P2P activities will result from a battery capacity increase of a specific magnitude when battery technology evolves.

Moreover, measurements on energy consumption during the sending and receiving of plain wireless data, when the device is not participating in an overlay network, help in designing new mobile-optimized protocols or new messaging patterns for the mobile usage of existing protocols. When the generic power consumption is known, it is possible to estimate a protocol's power consumption based on its traffic patterns.

P2P overlay networks can be structured – which in practice means that the network is based on distributed hash tables (DHT) – or they can be unstructured. We focus on structured overlay networks that have attained popularity in large P2P deployments thanks to their good scalability.

Some previous work on the energy consumption of mobile devices in structured P2P communications exists. In [1], the battery life of mobile peers in a very large Kademlia DHT based overlay is evaluated. It is shown that under the specified circumstances a mobile phone can operate as a full-fledged peer for a few hours. In addition, a client-only mode is introduced that allows mobile nodes access the overlay with minimal energy consumption. In [2], the energy consumption of mobile devices in a large DHT is reduced by selectively dropping incoming messages, still preserving compatibility with existing widely used DHTs. The mobile power consumption in non-P2P-specific cases has been studied more extensively, for example in [3] and [4].

We, in this paper, provide measurement data about power consumption of a state-of-the-art mobile device in both, the actual structured P2P overlay activities with different overlay parameters, and the plain (protocol-less) sending or receiving of UDP messages. The measurements are conducted in UMTS and WLAN (802.11b/g) access networks.

The specific DHT algorithm used in our measurements is Kademlia [5], and the chosen overlay-management protocol is the Peer-to-Peer Protocol (P2PP), which has been developed in the IETF as a candidate protocol for standardizing P2P networking. The design process of P2PP has been merged into that of the RELOAD protocol. The protocols have been developed in the context of the design work for peer-to-peer session initiation protocol (P2PSIP), the motivation and basic technological goals of which are discussed in [6].

The remainder of the paper is organized as follows. In Section II, we describe the experiment setup. The overlay-related power measurement results are presented and analyzed in Section III. In Section IV, we present the non-overlay-related power measurements. Discussion and future work are provided in Section V and the paper is concluded in Section VI.

II. EXPERIMENT SETUP

A. Server-based Overlay Simulation Environment

A sufficiently large P2P overlay was needed for each measurement case in order to evaluate the mobile nodes' battery life in a realistic environment. Thus, the majority of an

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overlay's nodes were implemented as a server-based simulation. For this purpose we used an array of Linux-based server machines (hardware: SunFire V20z, 2GB of memory, double AMD Opteron 248 at 2.2GHz).

The servers ran our prototype implementation of the P2PP protocol. The implementation is written in C++ and features the ability to take new DHT algorithms into use in a plug-in like manner. The only DHT algorithm implemented and used by us was Kademlia [5], where the XOR metric determines the logical distance of peers in the overlay address space. The used transport protocol was UDP. Each simulated peer had a unique combination of a server's public IP address and a UDP port number. Thanks to the public fixed IP addresses, there was no need to apply network address translation (NAT) traversal.

Some parameters of a simulated P2P overlay were constant and some were variable in order to study the parameters' effect on the battery life as well as on the overlay's average resource lookup efficiency, which will be discussed in our another publication. The constant overlay parameters were as follows.

The keep-alive interval was t_{KA} = 10s, the routing table exchange interval was t_{rtx} = 30s, and the publishing interval of resources was $t_{publish}$ = 30s. The selected timer interval values exist as recommendations in the Internet Draft of the P2PP protocol, thus they were considered a neutral choice for our simulation. It should be noted that there was exactly one resource published by each simulated peer, and the publishing was repeatedly refreshed with a new Publish request at the interval $t_{publish}$; at each Publish transaction the resource (key-value pair) was updated to a peer in the overlay as determined by the DHT algorithm. The published data resources' size was less than 20 bytes in order to make sure that the handling of large resources does not skew the measurements, as we wanted to focus on a baseline case where the nodes' load originates mostly from the basic functionality of the P2PP protocol.

The maximum number of items per k-bucket, an important parameter for the Kademlia protocol, was $k = 3$ following the choice made in the simulations in [7]. The number of parallel lookup requests was $\alpha = 1$ (no parallelism).

In order to attain a realistic simulation of an overlay environment, the *churn* behavior of the peers had to be modeled. Churn, i.e. the constant joining of new peers and leaving of old peers from the overlay, causing signaling overhead and temporary inconsistency of routing tables, is a characteristic of real-world overlay networks and a major factor affecting their performance [8]. We simulated churn by having the online and offline times of each peer follow the exponential distribution with the mean value t_{churn}. For example, in a simulation where t_{churn} = 60s, each peer stays online for an average of 60s, then offline for an average of 60s, and so on.

The variable overlay parameters were the number of peers N, the lookup request interval t_{lookup} [s], and the churn level t_{churn} [s]. Every node issued a lookup request for a resource with a randomly selected key (that was known to exist somewhere in the overlay) at every t_{lookup} seconds. The selected ranges of the variable parameters are shown in Table I. The selected range of t_{churn} represents relatively high levels of churn. It should also be noted that N is the total number of peers: the sum of online and offline peers. This means that at any moment averagely $N/2$ simulated peers would be online.

TABLE I. VARIABLE OVERLAY PARAMETERS

Symbol	Explanation	Value Range
N	Number of peers	200; 2000
t_{lookup}	Lookup resource interval	15s; 120s
t_{churn}	Churn: mean online or offline time	60s; 480s

B. *Mobile Peers*

In addition to the large number of server-simulated peers, there were two (2) mobile peers present in the overlay in every simulation scenario. These devices were Nokia N95 smartphones, equipped with UMTS and WLAN connectivities. They acted as full-fledged peers in the overlay, in addition to the N server-simulated peers. The mobile nodes had public IP addresses and ran the same P2PP implementation as the server-based nodes did; the implementation was written in cross-platform C++ code with minimal changes to enable its use on both Linux and Symbian OS Series 60, which is the operating system of the N95 phones. The overlay deployment with server-based and mobile nodes is illustrated in Fig. 1.

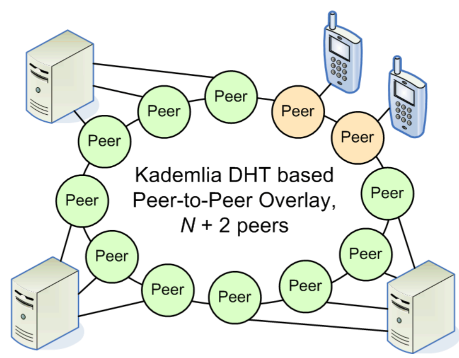

Figure 1. The overlay deployment. Mapping of the $N + 2$ logical peers to physical machines.

The mobile peers did not churn; they stayed online during the entire duration of the power measurement period, which was 20 minutes in every simulation. The mobile peers also did not publish any resources or issue resource lookup requests. They did, however, provide resource-related services to the other nodes according to the rules of the protocol and the DHT algorithm, because they were peers with full responsibilities. The aim was to observe the mobile peers' battery life in a baseline case where they only produce shared services in the overlay but do not consume the services themselves.

The power consumption of the phones was recorded with the Nokia Energy Profiler monitoring software. The Bluetooth connection was enabled (set "on") during the activities, but was not used by the protocol-running software or by the Energy Profiler. The Energy Profiler, in addition to measuring the battery consumption, was able to measure among other things the CPU load level and network traffic load. The measurements of the CPU and traffic loads during mobile P2PP usage are to be provided in another publication.

III. P2P-RELATED POWER MEASUREMENTS

There were $2^2 = 8$ combinations of the variable overlay parameters. As there were also two different wireless access networks to evaluate for the mobile nodes' energy consumption, a total of 16 simulation scenarios were run.

The power P_{avg} was measured as an average of the power consumption during each 20-minute measurement on the two mobile devices. Knowing that the battery capacity of an N95 was 950mAh and the average voltage level V_{avg} (nominal value 3.7V, measured values approximately 3.8V to 4.0V) was reported by the Energy Profiler software, we calculated the expected battery life of a mobile peer

$$T_{battery} = \frac{0.950Ah \cdot 60\frac{\text{min}}{h} \cdot V_{avg}}{P_{avg}} \text{ [min]}. \quad (1)$$

The measured power consumption levels and the calculated battery lifetimes are provided in Fig. 2 with the UMTS connectivity and in Fig. 3 with the WLAN connectivity. The signal levels of the both access network types were excellent at the location of the measurements.

Figure 2. Power consumption and the calculated expected battery life of mobile P2PP peers in a UMTS access network.

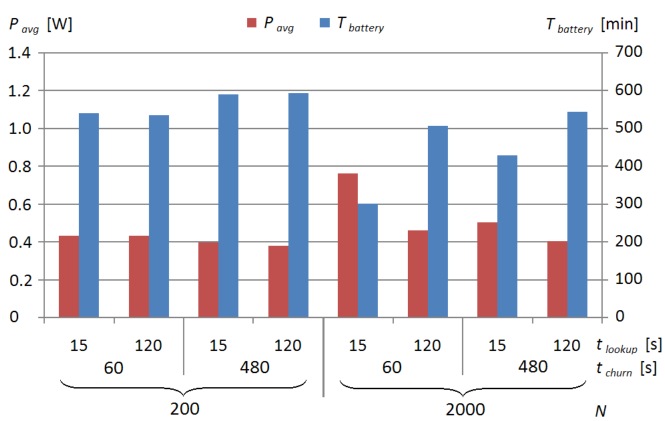

Figure 3. Power consumption and the calculated expected battery life of mobile P2PP peers in a WLAN access network.

The power consumption is higher in UMTS than in WLAN with the evaluated traffic patterns. It can also be noted that in UMTS the power consumption seems to be rather constant with all evaluated parameter combinations, while in WLAN in overlays of $N = 2000$ peers with a low resource lookup interval (t_{lookup} = 15s, high lookup activity level) the battery life of mobile peers clearly deteriorates.

IV. NON-P2P-RELATED POWER MEASUREMENTS

In order to enable the approximation of the energy efficiency of networking protocols devised for mobile usage in the future, we evaluated the power consumption of the two N95 phones (the same physical units as in the overlay-related measurements) in the sending and receiving of UDP packets. We used a specially crafted software that contained nothing but mechanisms for sending or receiving plain UDP packets of a specified size at a specified interval. Measurements were again done with Energy Profiler. When the other phone sent packets, the other one received them. For every measurement we also switched the roles of the phones, so that we obtained both power levels (sending and receiving) from both devices.

Two different UDP packet sizes, 100 bytes and 1000 bytes, were evaluated. The packet sizes were combined with six different sending and receiving intervals ranging from 50ms to 10000ms, yielding 12 combinations of those parameters. Power levels of sending and receiving in the plain-UDP measurements are shown in Fig. 4 for UMTS, and in Fig. 5 for WLAN.

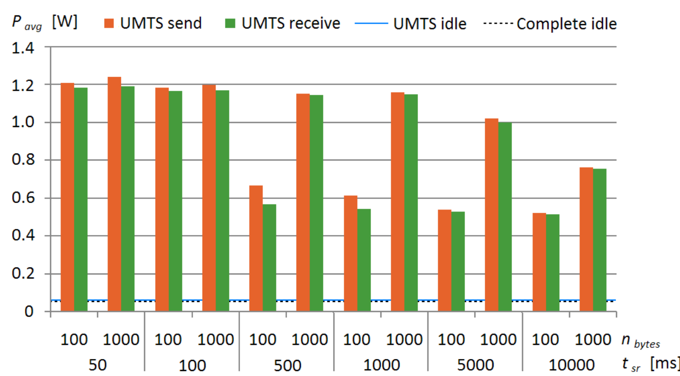

Figure 4. Power consumption of sending and receiving UDP packets in a UMTS access network, UMTS idling, and complete-idle state.

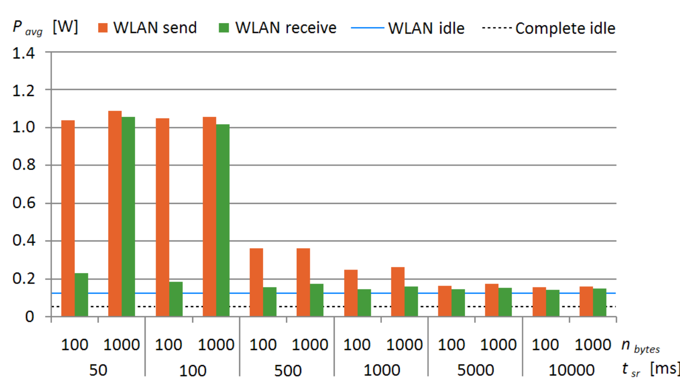

Figure 5. Power consumption of sending and receiving UDP packets in a WLAN access network, WLAN idling, and complete-idle state.

Due to the nature of the radio interfaces, we determined that we could not simply evaluate a correspondence between the data rate (bytes/s) and power consumption in the plain-UDP measurements. That is why we evaluated several different time intervals between the send or receive events, as the radio interfaces may go to different sleep states depending on the burstiness of the traffic, i.e., how long a time passes between events of data transfer (a property of any upper-layer protocol).

From the figures it is visible that there is a non-linear correspondence between data rate and power consumption. In addition to the sending and receiving measurements, the figures also show the power consumption in an idle state, where the network interface is kept on, but no data are sent or received; this power level was 0.062W for UMTS and 0.128W for WLAN. Furthermore, the power consumption in a "compelete-idle" state, where no network interface is on, is provided; this was measured to be 0.056W. These values provide perspective for understanding whether a particular power level during network activities is high or low compared to non-networking activity. It can be seen from the results that the idle power consumption in UMTS is lower than in WLAN, but WLAN beats UMTS in energy efficiency in all other evaluated cases.

V. Discussion and Future Work

For longer mobile battery life, improvements in networking software and hardware and in battery technology are needed. Since supercapacitor-based mobile energy-storage devices are still a technology of the future, a realistic example of a useful improvement could be a connectivity management system that switches from UMTS to WLAN when possible, to lengthen the average battery life of mobile peers. Of course the upper bound of the thus attainable battery life is the battery life in WLAN.

The plain-UDP power measurements have been applied in the estimation of mobile devices' battery consumption, as part of energy-aware load balancing related simulations of P2P overlay networks, in a study that is to be published. Additional plain-UDP power measurements are needed to approximate the power consumption in cases where both sending and receiving are done by the same mobile device. It should be noted that any formulas that take the plain-UDP power data and an arbitrary protocol's messaging patterns (network traffic) as input, providing estimated battery life as the output, can be verified by comparing their results to actual measurements of the power consumption of that traffic.

Battery life measurements with an unchanged protocol implementation but with different parameters – especially with less active overlays than our already evaluated cases – are needed. Evaluating a broader range of activity profiles i.e. the combinations of different frequencies of maintenance, publish, and lookup messaging, may lead to finding sweet spots where battery life is substantially longer. In addition, the battery life when using a mobile-optimized P2PP protocol implementation on the mobile peers or even in the entire overlay (as the actions of remote fixed-line peers affect also the mobile peers in the same overlay) is an interesting subject of measurement.

It should be noted that in real-life networks especially UDP connections often require the repeated refreshing of NAT bindings; a binding may expire in minutes if the NAT observes a connection to be inactive. This justified selecting a relatively short keep-alive interval for the evaluations in this paper.

VI. Conclusion

The power measurements indicate that a mobile device can act as a peer in an active, Kademlia-based P2P overlay for about 3 hours with UMTS connectivity and 5 to 10 hours (about 8 hours in an average of the cases) with WLAN connectivity. This speaks in favor of using WLAN for P2P activities, if it is available: with a full battery, a mobile device can operate as a peer for roughly one working-day.

The battery life seems short, and the power is needed also for other usages besides P2P networking. However, it should be noticed that the chosen parameter range in the simulations resulted in a relatively high amount of overlay activity: for example, the keep-alive and routing table exchange messages were sent at a fast pace. Although the values are from the Internet Draft, practical timer values could be minutes rather than tens of seconds, if NAT bindings (or similar factors) are not an issue. Moreover, battery life can be longer with different devices, different protocols, or optimized protocol versions.

The plain-UDP power measurements provide a basis for estimating the power consumption of UDP-based protocols without protocol-specific power measurements on mobile devices. Further measurements and algorithms for applying the data with the traffic patterns of a given protocol are needed.

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