Energy Efficiency of Mobile Device Recharging

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ABSTRACT
Because of losses in electricity conversion and storage only part of the energy taken from the power grid produces useful work in a battery-operated mobile device; the rest evaporates as heat. We analyze the recharging activity of a mobile phone to understand the efficiency of the different units involved (charger, EPM chipset, battery). Our measurements show that the efficiency is quite low; only about 15% of the electricity from the power grid ends up being used for the actual computing and communication elements of the mobile phone. It seems that there is room for improvement in the recharging efficiency. However, as the consumption of electricity of a single phone is small the incentive for improvements has been weak.

Keywords: Energy; Power; Recharging; Efficiency; Mobile phone

INTRODUCTION
The number of battery-operated mobile devices is increasing rapidly. The common issue for most of them is the need to recharge the batteries using power taken from power grid or other source of electrical power. One of the fundamental issues is the efficiency of converting the energy from power grid to useful work. In other words, how many Joules of energy is taken from the power grid to produce one Joule of work when using the device.

The primary perspective of studying mobile phone energy consumption has been how to make the battery last longer. Given the slow improvement in battery storage capacity (Robinson, 2009), R&D activity has focused on reducing the energy consumption of the mobile device use with more power efficient components and smarter use of energy. For phone users this means less need to worry about recharging and improved user satisfaction.

The other perspective has its roots on the increasing cost and concern related to electricity consumption of the ICT sector. The energy-efficiency of data centers, data communication networks, and end-user devices, like PCs, has become important. So far, there has not been much interest towards the electricity consumption of mobile devices, probably because the electricity consumption of a mobile phone is small in comparison to more power hungry elements involved in the end-to-end communication.

In this study our focus is on the latter perspective. The energy taken from the power grid is converted into useful work in the mobile device in multiple steps. Each step involves some losses

1During the execution of this research Kari Rissanen was working at Nokia Research Center.
where part of the energy is wasted as heat warming up the charger and the mobile phone. In this work we want to quantify the losses and understand how efficiently the mobile phone is able to use the electricity it takes from the power grid. We analyze and measure the key units involved (charger, EPM chipset, battery) to understand how much energy is lost in each step. In this way we can estimate both the overall efficiency and the efficiency of the individual steps. Furthermore, we can apply efficiency estimates to study how much regular activities, like calling, browsing, or music listening, require the mobile phone to take electricity from the power grid.

To differentiate between the two perspectives we use the following terminology in this paper. When we speak about electricity, and electricity consumption, we refer to the power that is taken from the power grid. When we speak about energy or power consumption we mean the consumption of energy taken from the phone battery and consumed by the applications and services of the mobile device.

Understanding the relationship between the energy consumed by the applications and the electricity taken from the power grid is important for several reasons. First, the increasing interest towards the environmental load of ICT devices makes the recharging electricity of mobile devices relevant, especially because of the cumulative effect of the high number of mobile devices. The energy consumption of different mobile applications has traditionally been the focus of study because it dictates how often users need to recharge their devices which directly impacts the user experience. Now this perspective is complemented with better understanding what the energy consumption of applications means in terms of electricity from the power grid. Second, explicitly mapping the energy chain and quantifying the efficiency ratios of different components is useful for understanding the whole energy chain. This can also be a basis for further development and analysis of more efficient recharging solutions.

This paper is an extended version of our conference paper (Ruutu et al., 2011). As far as we know there are no other prior studies of the joint energy efficiency of the different components involved in the recharging process. The energy efficiency of different components has been studied in isolation: chargers (e.g. Ostendorp et al., 2004; Weier and McMahon, 2007), energy and power management chipsets (e.g. Chen et al., 2009), and battery (e.g. Lopez et al., 2004; Pedram and Wu, 2002). However, forming the big picture from the isolated studies that use different platforms is difficult. By analyzing all of the components in one study we are able to understand the relative importance of the different components for the overall efficiency.

The rest of the paper is structured as follows. In the next section we specify what we mean with efficiency, create a model for energy chain, and formulate it mathematically. This is followed by a section where we review related work on energy consumption of mobile handset and on efficiency ratios of different parts of the energy-chain. We then describe our measurement arrangements and present the measurement results. We use the results to analyze the electricity consumption of some use cases in the Energy consumption of sample use cases section. In the Discussion section we discuss our findings and in the Conclusions section we summarize the key findings and propose ideas for further research.

**MODEL FOR ENERGY CHAIN**

A number of steps are needed before the electricity taken from power grid is available for useful work in the circuits of a mobile device. These steps form the energy chain where energy is
converted into different forms needed for storage or for use in the next steps. Figure 1 shows our model of the energy chain and the different steps involved. The main steps are as follows:

1) A charger converts AC current from the power grid to DC current.
2) DC current from the charger is regulated by Energy and Power Management (EPM) chipset of the mobile device into battery charging current.
3) Battery charging current is converted to chemical battery energy.
4) Chemical energy stored into battery is converted into the battery current to power up the hardware components of the device.

Referring to Figure 1, we use the following notations in this paper.

- $E_{grid}$ is the energy taken from the power grid
- $E_{charger}$ is the energy provided from the charger to mobile device
- $E_{recharge}$ is the energy that EPM chipset drives to battery during recharging
- $E_{battery}$ is the energy taken from the battery during usage.

In mathematical terms, we are searching for the following efficiency ratios:

\[
\alpha_{charger} = \frac{E_{charger}}{E_{grid}}
\]

\[
\alpha_{chipset} = \frac{E_{recharge}}{E_{charger}}
\]

\[
\alpha_{battery} = \frac{E_{battery}}{E_{recharge}}
\]

Finally, we define the overall efficiency as

\[
\alpha_{total} = \frac{E_{battery}}{E_{grid}} = \alpha_{charger} \alpha_{chipset} \alpha_{battery}
\]

Strictly speaking, the efficiency rates above can be a function of various parameters since typically the conversion of electrical energy from one format to another depends on output voltage, current etc. However, we refer here to the average efficiency rates over the whole recharging event. Thus, the numbers reflect the rates over several hours. Note that in this work we only focus on the phase when the active recharging is taking place. The electricity consumption of the connected charger after the battery is fully loaded is a topic for a separate study.

RELATED WORK

As far as we know there are no prior studies on the efficiency and electricity losses of the whole mobile device recharging system. A number of studies investigate some parts of the recharging process but no prior study seems to cover all the elements of the recharging process. The task of estimating the energy consumption of recharging is complicated because it depends on many attributes. The battery with an internal impedance and the recharging circuitry with its
impedance form a system whose efficiency is a function of recharging amplitude, frequency range specified by the recharging waveform and recharging pattern. Furthermore, the impedances are functions of the battery charge level and temperature. Also, losses in battery operation differ from those of direct operation i.e. the device connected in mains with a charger. A precise modeling of this kind of a complex system calls for a complex model calibrated with an extensive set of measurements. In the present study our goal is more to form an overall understanding of the system rather than a highly detailed model capturing all factors and dependencies.

In the following section we review relevant prior work. The number of influencing factors is large and the related works range from users’ recharging behavior to battery chemistries.

Recharging behavior of mobile device users

Research on recharging behavior of mobile phone users is a growing study area. Ferreira et al. (2011) assessed the recharging behavior of a large sample of Android users, but reported only limited details on their behavior. Rahmati et al. (2007) analyzed what they call human-battery interaction. One of their results was classifying users into two groups with different behavior: those who follow a regular recharging schedule and those who base their recharging decisions on the battery level feedback of the mobile phone. Heikkinen and Nurminen (2010) performed a questionnaire study of the recharging behavior of 150 university students. Oliver (2010) studied data collected from Blackberry users with the focus on the charge and discharge durations and the recharging behavior.

In general we can conclude that a growing amount of results on the recharging behavior is available. Although it is not directly applicable to the present study, it is important for two reasons. First, the data tells us how relevant the active recharge time is, in comparison to the time when a fully charged phone is still connected to the charger or a plugged-in charger is disconnected from the phone. The focus of our present study is only on the active recharging phase. Understanding the active recharge time share is important for understanding how relevant active recharging energy consumption is for the total phone energy consumption. Second, the studies tell what are the important issues for the phone users. Clearly the convenience of less frequent recharging is important. Although, some users are concerned with the environmental impact, it is clearly a minor issue. Therefore, there is little direct user demand to improve the energy efficiency of recharging.

Mobile communication system energy consumption

A number of studies have investigated the electricity cost and environmental impact of mobile networks and mobile devices.

Skerlos et al. (2003) refer to a bit dated study from year 2000 by Motorola, which examined the energy consumption of a mobile handset in use-phase and estimated it to be 56Wh/day. This includes calling, charging, and both handset and charger standby. Etoh et al. (2008a) studied the total energy consumption of the largest mobile telecommunications operator in Japan in 2006 and estimated that an average customer’s phone consumes 0.83 Wh per day whereas the mobile network consumes 120 Wh per day per customer. Schaefer et al. (2003) estimated the German mobile telecommunications sector to consume 79.5 Wh per day per subscriber in 2000, phones being responsible to 36 Wh of the consumption. Fehske et al. (2011) have investigated the global impact of mobile communications. They estimate that recharging of regular mobile phones consumes 5.5 kWh/day and recharging of smartphones goes up to 19.2 kWh/day. In comparison
to other elements in mobile networking the share of carbon dioxide emissions of phones is small but is expected to grow. The discrepancy between these studies illustrates the challenge of estimating the power consumption of mobile telecommunications technologies. Correia et al. (2010) investigate the electricity consumption of base stations in cellular access networks. They observe that losses from the power supply are responsible for 5-10% of the total power consumption of the base stations while the power amplifier dominates the power consumption with 50-80% share. Although participating in the same radio communication, the architecture and design goals of mobile phones and base stations are completely different, and therefore the numbers are not comparable. As mobile services are increasingly using resources residing in the Internet, the energy consumption of the Internet and the data centers connected to it is becoming increasingly relevant to understand the overall picture of the energy consumption of mobile services (Baliga et al., 2007; Koomey, 2008).

**Charger**

Some previous work has quantified the energy efficiency of chargers for mobile phones (Ostendorp et al., 2004; Weier and McMahon, 2007). Ostendorp et al. (2004) measured the efficiency of different chargers. They found that the efficiency of chargers had improved from 52% in year 2002 to 62% in year 2004. Weier and McMahon (2007) investigated the charger energy consumption in different states (charging, connected to a fully charged battery, disconnected). They found that in the active charging state the losses were around 1 W to 2 W. The focus of their study was the losses only and they do not report any efficiency figures or total energy consumption of the chargers. They also compared measurement methodologies: calorimeter measuring the emitted heat of the charger and oscilloscope measuring the voltage drop.

Aebischer & Huser (2002) investigated the power supply units of PC computers (unfortunately quite old models from 1990-2001) and found that the power supply efficiency converges towards 80% efficiency. When the system is lightly loaded and the operating point is below 20% efficiency.

There also exists a calculator for the energy efficiency of the power supplies http://www.powerint.com/greenroom/ regulations-application/cell-phone-chargers.

**Chipset**

Chen et al. (2009) have investigated the recharging efficiency of Li Ion batteries. Different mechanisms have different gains starting from 55% efficiency and going up to 91% efficiency with the new solution they propose.

**Battery**

A number of papers study and model the battery operation. The battery efficiency depends both on the recharging strategy and on the discharging strategy. According to Lopez et al. (2004) the efficiency of a lithium ion battery is about 85%-90% depending on the charging rate. According to Pedram and Wu (2002) the efficiency varies between 60%-95% degrading with higher discharge currents.

Most of the papers on battery performance focus on two issues that are important for user experience. The target is both to minimize the recharging time and maximize the amount of energy available in the battery (Pedram & Wu, 2002). The perspective, how much electricity is
actually needed to charge the battery has received less interest traditionally probably because it does not have a clear link to user satisfaction.

**MEASUREMENT SETUP**

We have made a set of measurements with a smartphone to clarify the problem statement. The smartphone used was Nokia N97 with AC-10E charger that has a micro-USB interface. The mobile device has a battery of 1500 mAh nominal capacity that corresponds to about 20 000 J. The measurements have been made using the following methods:

1) Measurement of energy ($E_{grid}$) taken from power grid was made using digital oscilloscope with a magnetometer-sensor based current measurement around the power cord.

2) The energy $E_{charger}$ provided from the charger was measured using the same digital oscilloscope and sensor.

3) Energy from $E_{recharge}$ going to battery was measured using current sensor connected to the battery using Nokia Energy Profiler (Creus and Kuulusa, 2007).

4) Finally, energy $E_{battery}$ taken from battery for useful work was measured also using Nokia Energy Profiler.

**MEASUREMENT RESULTS**

Table I shows the measured efficiency rates; how energy is lost in different stages of the process. The left column shows the measured efficiency of each individual step. The right column shows the cumulative effect of the losses in the energy chain for the total efficiency. Because the total efficiency is the result of the multiplication of the different efficiencies, it declines rapidly and is only around 15%. It is clearly visible that the battery is the weakest link with only 30% efficiency.

In comparison to prior research, the charger and chipset results are well in line with earlier studies (Chen et al., 2009; Aebischer & Huser, 2002). Battery efficiency is worse than what the prior studies (Lopez et al., 2004; Pedram & Wu, 2002) indicate. As the measurement setup with the Nokia Energy Profiler is different from the measurement arrangements of prior studies the battery efficiency figure should be taken with some care. However, higher battery efficiency would not drastically change the end result; the overall efficiency of the energy chain is well below 50%.

**ENERGY CONSUMPTION OF SAMPLE USE CASES**

With the measured efficiency rates of previous section we are able to estimate how much energy is needed for different actions that users perform with their mobile phones. Table II shows how much energy is needed for voice calls, music listening, and file download. In addition to the energy the table also shows the monetary cost of different use cases. For the cost calculation we have used 0.15 Euro/kWh, which is rough approximation of the electricity cost in Finland. Different regions naturally have different tariffs but the order of magnitude is probably representative of electricity prices in developed countries. These are examples of different uses of the mobile phone. It is clearly evident that the energy consumption is small. Also the monetary cost of electricity to use a mobile phone is negligible in comparison to costs of purchasing the device and paying for the subscription in a typical urban
environment with a working infrastructure. Therefore it is unlikely that the electricity consumption of a mobile phone would have any effect on the user behavior. For instance, paying extra for a phone model with a better recharging efficiency would be meaningless for most users. Notice that the electricity consumption of a mobile phone is a different issue from the power consumption of the different applications. Smaller power consumption of the mobile phone applications directly translates into less frequent need to recharge and, in this way, into user experience.

However, as the number of mobile subscribers is large, the cumulative electricity consumption of the mobile phones of the world starts to be meaningful. An improvement in the recharging efficiency would cut the cumulative electricity consumption of mobile phones. Alternatively, more energy-efficient operation of mobile applications would result both in electricity savings and in improved user satisfaction. Because the latter aspect is clearly visible to the end user there is a clear motivation for different phone manufacturers to compete on the energy-efficiency of their devices. Because the recharging efficiency is largely invisible and irrelevant for the end users recharging efficiency may not be as tightly optimized as energy consumption of mobile applications.

However, there are a number of cases where recharging efficiency can be meaningful for individual users. First, if recharging efficiency would influence the recharging time, it would be a clear motivator to favor more efficient recharging procedures. However, without further research it is hard to say if faster recharging would actually require more electricity consumption. Second, in places where access to electricity is scarce the electricity consumption starts to be meaningful. This is the case in emerging markets where part of the dwellings or villages are not connected to the power grid at all. Likewise, if electricity is generated by the users, e.g. via bicycle dynamos, or other muscle based mechanisms, or if electricity generated depends on nature, such as solar panel or wind generators, or extreme cases like manual transportation of a set of loaded car batteries to a village for a temporary power source for enabling the operating and the charging of mobile devices, the more efficient recharging solutions would be more valuable. As mobile phones are spreading to new markets these aspects may become increasingly important. Finally, a growing number of people are environmentally conscious and for this market segment the more efficient recharging would be a sale argument.

An additional measure of recharging efficiency is to estimate how much electricity is needed to fully recharge an empty battery. Here, an empty battery refers to a battery with the voltage that is at or below the threshold called cut-off voltage i.e. device power-down voltage. Here, a full battery refers to a battery with the voltage at the upper threshold i.e. the stop-charging point, correspondingly. These two thresholds are typically controlled by the energy and power management circuitry in order to provide a reasonable compromise between battery lifetime and the amount of energy stored in the battery. Table III shows examples of different phone models battery sizes and recharging energies. The table is computed with the assumption that the energy losses in the energy-chain are similar for the different phone models.

We can use table III to derive an estimate of the daily energy consumption of the mobile phone. If we assume that people recharge their devices every day and recharging would start from empty battery then the above figures would reflect the electricity consumption that a mobile phone causes (excluding the network and service infrastructure). The range of values (7-12 Wh) is likely to be an upper limit as many users do not recharge everyday and recharging is normally not starting from a completely empty battery. We estimate therefore the daily consumption to be in the range of 2-5 Wh.
It is interesting to compare these figures with the numbers with the ten year earlier estimate of 56 Wh/day (Skerlos et al., 2003). On one hand, because of hardware and other advances modern mobile phones are consuming less energy for the same tasks than older models. On the other hand, the usage patterns have changed considerably with the introduction of new services and features, like email, browsing, navigation, or camera. In the light of our present study the earlier estimate might have been a bit too high.

DISCUSSION

USB charger and Li-Ion batteries are commonly used in the consumer electronics industry and we believe that these results give indications to behavior of other devices using the same technologies. The observed total efficiency may appear low if only the absolute value is looked at. This is related to three fundamental issues.

- First, there is currently no real alternative for battery if the device needs to be mobile. Thus, the losses associated with the recharging process cannot be avoided at the moment.

- Secondly, at least the first step of the recharging process occurs anyway in most electrical devices that use the AC current of power grids but need low voltage DC current for their components. Thus, a component similar to the charger is needed, such as power source of a PC computer. This is likely to have similar kind of efficiency rates as a charger.

- Thirdly, most mobile devices are designed from the very beginning with energy-efficient components and architectures and they execute typically aggressive power saving methods. Thus, although there are battery related losses in mobile devices, the circuitry of a battery-operated mobile device is likely to use less energy for the same operations than the circuitry of a fixed device with direct power-feed from the grid.

It is clear that the recharge efficiency of a single phone has only small influence on the energy consumption. Nevertheless, the large community of phone users makes the cumulative impact significant.

It is also important to note that the energy consumption of the mobile phone is very small in comparison to the energy consumption of the cellular infrastructure. For instance, measurements in Japan (Etoh et al., 2008b) show that the cellular infrastructure consumes 120 Wh per day per cellular subscriber. This is over ten-fold the daily energy consumed by the mobile phone that we, in section VI, estimate to be 2-5 Wh. Thus, more efficient usage of cellular infrastructure and the associated resources would probably have bigger impact than improving recharge efficiency alone.

In comparison to prior studies on charger energy efficiency, our measurements showing 70% efficiency for the charger indicate improvements over prior studies, which in 2004 (Ostendorp et al., 2004) found the average efficiency of chargers to be 62%. Because our study was not focused on charger behavior we only measured a single charger model. Therefore this observation has to be taken with some care.

The efficiency of data centers is often measured with power usage efficiency (PUE). It is calculated by dividing the facility’s total power consumption with the power used only by server, storage systems, and network gear (Katz, 2009). Modern data centers can reach values as low as 1.15 but much higher values are common in less modern facilities. Although the scale and architecture is completely different, the ratio between electricity needed by the phone and the power used by the phones circuitry is an analogous measure. With the values of Table I we can
calculate the “PUE figure” for a mobile phone and see that is as high as 7.1. Of course these values are not directly comparable. Data centers spend a considerable amount of energy on cooling which is not needed for mobile devices at all. On the other hand, part of the power consumed by the IT equipment in the original definition of PUE may be lost in internal conversions within the computing equipment. However, it seems that a figure, similar to PUE or total efficiency percentage, would be useful to characterize and compare the energy use of different equipment.

CONCLUSIONS

We have shown that about 14 % out of power grid energy is used for the actual operation of a Li-Ion battery-operated mobile device. This means that to produce 1 Joule of useful work, the power grid needs to provide 7.1 Joules. This has implications both for the environmental influence on the mobile phone use and for the engineering of power systems for mobile devices. With improvements in the efficiencies of different components of the recharging chain it should be possible to create major savings. Especially when electricity is scarce, like in emerging markets, improvements could be of major value also for the end users.

The study also shows that analyzing of the efficiency of chargers only is too limited a view. The other parts of the energy flow in the system have also major losses, and therefore they are good candidates for improvements.

The number of recharging alternatives is increasing. In the past there was typically only one way to recharge a mobile while many devices today can be charged both via a special charging socket as well as USB. Understanding the difference between these alternatives is useful and can also influence the selection of the optimal recharging alternative for the user when multiple options are available. Finally, when the mobile device is recharged from the battery of another device, e.g. from the electricity coming from the batteries of a laptop, it is good to understand how much energy consumption recharging causes for the device that acts as the source of energy.

ACKNOWLEDGMENTS

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REFERENCES


Figure 1. Chain of energies with a mobile device

Table I MEASURED EFFICIENCY RATES.

<table>
<thead>
<tr>
<th></th>
<th>Efficiency (%)</th>
<th>Energy left (%)</th>
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<tbody>
<tr>
<td>$E_{\text{grid}}$</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>$E_{\text{charger}}$</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>$E_{\text{recharge}}$</td>
<td>72</td>
<td>51</td>
</tr>
<tr>
<td>$E_{\text{battery}}$</td>
<td>27</td>
<td>14</td>
</tr>
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</table>

Table II ENERGY CONSUMPTION OF EXAMPLE USE CASES

<table>
<thead>
<tr>
<th></th>
<th>Voice call (2 min)</th>
<th>Music player (1h)</th>
<th>File download (3MB with 100 kB/s)</th>
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</thead>
<tbody>
<tr>
<td>Average power (W)</td>
<td>0.82</td>
<td>0.13</td>
<td>0.30</td>
</tr>
<tr>
<td>$E_{\text{grid}}$ (J)</td>
<td>707</td>
<td>3385</td>
<td>65</td>
</tr>
<tr>
<td>$E_{grid}$ (Wh)</td>
<td>0.12</td>
<td>0.94</td>
<td>0.02</td>
</tr>
<tr>
<td>-----------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>Electricity cost (Euro) (0.15 Euro/kWh)</td>
<td>0.000029</td>
<td>0.00014</td>
<td>0.0000027</td>
</tr>
</tbody>
</table>

Table III ELECTRICITY NEEDED FOR COMPLETE RECHARGING OF DIFFERENT PHONE MODELS

<table>
<thead>
<tr>
<th></th>
<th>Capacity (mAh)</th>
<th>Recharging energy (Wh)</th>
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</thead>
<tbody>
<tr>
<td>Nokia N97</td>
<td>1500</td>
<td>11.54</td>
</tr>
<tr>
<td>Nokia N95</td>
<td>950</td>
<td>7.31</td>
</tr>
<tr>
<td>Nokia N900</td>
<td>1200</td>
<td>9.23</td>
</tr>
</tbody>
</table>
Addresses

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Jussi Ruutu works as Distinguished Research Leader at Nokia Research Center in Helsinki, Finland. He has 15 years experience with various technologies related to mobile devices and networks. In addition to Nokia Research Center, he has been working for Nokia Mobile Phones and Nokia Technology Platforms - units. Recent experience includes energy and power management as well as prototyping cognitive radio systems. Jussi received his M.Sc. degree in 1992 and Ph.D. degree in 1996 from Helsinki University of Technology.

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Jukka K. Nurminen started as professor of computer science at Aalto University at the beginning of 2011. He has a strong industry background with almost 25 years experience of software research at Nokia Research Center. Jukka’s experience ranges from mathematical modeling to expert systems, from
network planning tools to solutions for mobile phones, and from R&D project management to tens of patented inventions.

His current research themes are related to services and applications in distributed systems with an emphasis on mobile solutions. Peer-to-peer technologies and energy-efficiency research are of particular interest.

Jukka received his M.Sc degree in 1986 and Ph.D. degree in 2003 from Helsinki University of Technology.

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Kari A. Rissanen started as Program Director at Helsinki Region Transport in the beginning of July 2011. He has a strong industry background with 22+ years experience at Nokia. In addition, he acts as an independent consultant for high technology and sustainable development sectors. Kari’s experience ranges from multi-site line and program management, strategy and business development and establishing international organizations, technology scouting and innovation acceleration, to sales, education, engineering, patenting, developing and prototyping solutions for mobile multimedia communications, consumer electronics, mobile phones, networks, and computer-systems.

His current research themes are related to the development and establishment of a novel, energy efficient and environmentally friendly, demand driven public transport service with an emphasis on mobile client server architectures. Personal and flexible transport service enabling more passenger kilometers with less vehicle kilometers is of particular interest.

Kari received his M.Sc degree in 1988 and Lic.Tech. degree in 1991 from Tampere University of Technology.