Application

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2015-04357 Jakobsson, Martin NT-14

Information about applicant

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Project site: Inst för informationsteknologi

Information about application

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Project title (english): An investigation about the significance of packet size on the packet delivery ratio in wireless communications

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Keywords: packet delivery ratio, packet error rate, bit error rate, link quality estimation, packet length optimization

Funds applied for

Year:	2016	2017	2018	2019
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Descriptive data

Project info

Project title (Swedish)*

En undersökning av paketstorlekens betydelse för paketförlusterna i trådlös kommunikation

Project title (English)*

An investigation about the significance of packet size on the packet delivery ratio in wireless communications

Abstract (English)*

In most wireless networks, it is important to understand the quality of the links. This problem is called link quality estimation (LQE) and the LQE information is needed in order to decide the best path though a network, the right level of forward error correction coding, what transmission power to use, which transmission rate to use, and more. These are areas that are crucial to the performance of wireless systems, such as WiFi networks, wireless sensor networks (WSN), ad hoc networks, and other mesh networks, but also single wireless links.

Many wireless communications protocols, such as all WiFi (IEEE 802.11) versions, Bluetooth, IEEE 802.15.4 (often used in WSNs), can send packets of different lengths. The length of the packets has a big impact on the packet error rate. For higher layers, packet error rate is the most important. Until recently, this was an understudied issue. In a recent article, the applicant has shown how typical wireless links using different technologies and in different environments behave with respect to different packet sizes and constructed a simple model for this. This work clearly show that the packet error rate can vary significantly based on packet sizes. However, the work also shows that in some scenarios, there is no difference between different packet sizes. Hence, estimating the packet error rate for a given packet length based on observations from another packet length is non-trivial. Unfortunately, too many LQE mechanisms ignore this and simply assume the same packet error rate among all packet lengths, others may assume that the difference between large and small packets always are the same. In the article, the applicant has empirically shown that neither approach is sufficient in the general case.

In this project, this new knowledge will be used to design better LQE mechanisms that take packet size into account. The focus is on hello protocols, observing the delivery of data packets, and using information from coding to find improved LQEs. These new LQE mechanisms could be used in a wide range of wireless networks, such as WiFi networks, ad hoc networks, and WSNs. The project will also investigate how higher layer protocols and mechanisms should use the extra information or be redesigned. This includes mechanisms, such as transmission power control, modulation/coding selection, packet length optimization, automatic repeat request, routing, and other cross-layer aware mechanisms.

The project will be four years long and use one PhD student in addition to the applicant. The methodology to be used in this project is mainly prototyping and experimental measurements. Simulations and mathematical modeling will be used where applicable. The goal of the project is to improve the throughput, reduce delays, reduce energy consumption, and increase robustness in wireless communications and networking.

Popular scientific description (Swedish)*

Trådlös kommunikation blir viktigare och viktigare för varje dag. I framtiden kommer miljarder med nya enheter att bli uppkopplade till Internet och merparten kommer att bli uppkopplade trådlöst. Datatrafiken som går över våra datanätverk, inklusive de trådlösa nätverken, är uppdelade i paket. Ibland kan det uppstå fel i ett paket, en eller flera bitar (”ettor” och ”nollor”) kan bli fel i överföringen. Då plockar nätverksstacken bort det paketet och begär en omsändning. Detta funkar oftast bra, men kan innebära stora prestandaförluster när många paket innehåller även enstaka bitfel.

Ett beslut som nätverksutvecklarna gör är hur långt ett paket ska vara. Vissa trådlösa kommunikationsteknologier tillåter att paketen kan variera i storlek, men med en övre gräns. Exempel på detta är WiFi (även kallade WLAN) där paketen typiskt varierar upp till 1500 bytes. De flesta radioprotokollen för trådlösa sensornätverk tillåter också detta, men ofta bara upp till 127 eller 255 bytes. I dessa fall är det mjukvaran (t.ex. applikationen) som bestämmer vilka paketstorlekar som ska användas.

Större paket innehåller givetvis fler bitar som kan bli fel. Det innebär att chansen att minst en bit i ett paket är fel och måste plockas bort ökar när paketets storlek ökar. Tyvärr är detta ett faktum som ofta har ignorerats av nätverksdesigners och i de fall där hänsyn tas till paketstorlekarna har man gjort för stora förenklingar. Båda detta leder till felaktigheter och får givetvis konsekvenser på prestandan. I en ny studie har vi mätt upp exakt hur paketstorleken påverkar paketförlusterna för typiska trådlösa länkar. Flera tekniker och omgivningar har testats. Från denna studie har vi skapat en enkel matematisk modell som beskriver detta samband.

I detta projekt tittar vi mer specifikt på vilka konsekvenser detta får på prestandan hos trådlösa länkar och datanätverk samt hur vi kan designa nätverksprotokollen så att vi får optimal prestanda. Dels försöker vi hitta bättre metoder för att fastställa en länks kvalitet för olika paketstorlekar och dels hur denna information bör användas av övriga protokoll högre upp i protokollstacken. Det senare innefattar saker så som val av överföringshastighet, val av paketstorlek, och använd transmissionseffekt, men även routing. Målet är att göra trådlös kommunikation snabbare och mer pålitligt, samt minska fördröjningarna och sänka energiåtgången.

Project period

Number of project years*

4

Calculated project time*

2016-01-01 - 2019-12-31

Deductible time

Deductible time

Cause	Months

Career age: 81

Career age is a description of the time from your first doctoral degree until the last day of the call. Your career age change if you have deductible time. Your career age is shown in months. For some calls there are restrictions in the career age.

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes*	2. Teknik > 202. Elektroteknik och elektronik > 20203. Kommunikationssystem 2. Teknik > 202. Elektroteknik och elektronik > 20204. Telekommunikation

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Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

packet delivery ratio

Keyword 2*

packet error rate

Keyword 3*

bit error rate

Keyword 4

link quality estimation

Keyword 5

packet length optimization

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

This project is of a technical nature. No concerns of ethical nature can be anticipated.

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

An Investigation of the Significance of Packet Size on the Packet Delivery Ratio in Wireless Communications

Purpose and Aims

In most wireless communication networks, it is important to understand the quality of the wireless links. This information is needed in order to decide the right level of forward error correction (FEC) coding, what transmission power to use, which transmission rate to use, the best path though a network, and more. These are areas that are crucial to the performance of wireless systems, such as wireless sensor networks (WSN), ad hoc networks, mesh networks, but also single wireless links. The process of identifying a link's quality is known as *link quality estimation* (LQE) and has been a frequent topic of study [1-3,J1,J2].

Many wireless communications protocols, such as all WiFi (IEEE 802.11) versions, Bluetooth, IEEE 802.15.4, DASH7 (ISO/IEC 18000-7:2009), can send packets of different lengths. The length of the packets has a big impact on the packet error rate. For higher layers, the packet error rate is the most important aspect from the lower layers. Unfortunately, the impact of packet size on packet losses is an understudied issue. Previous research has shown that packet length has an impact on the delivery ratio; longer packets have a larger chance of getting corrupted [4]. This can significantly affect wireless networks. For example, it has been shown [5] that using hello packets of the same length as the data packets instead of very small hello packets can improve the end-to-end performance in multi-hop networks by between 60.7% and 80.8% due to better route selection. Hence, making link quality estimates for a given packet length based on observations from another packet length is non-trivial. Unfortunately, too many LQEs ignore this and simply assume the same delivery ratio among all packet lengths. Others use a simple formula based on bit error rate and assuming independent bit errors, as follows:

$$PER = 1 - (1 - BER)^L \qquad (1)$$

where, BER is the bit error rate, L is the packet length in bits, and PER is the packet error rate. In a recent paper [J3], the PI has shown that these assumptions are too simple. By empirical measurements of several wireless technologies in many different scenarios, we can conclude this based on statistical analysis. Fig. 1 shows a representative measurement campaign from [J3], where every line is a static link. We can see that the packet delivery ratio (PDR – the inverse of PER) indeed decreases with increasing packet length, but with a large variation among the different links and scenarios. To account for this, it is necessary to introduce a packet length-independent component to (1). We re-write model (1) as follows [J3]:

$$p_L = p_0 \cdot p^L \qquad (2)$$

where L is the packet length in bytes, p_L is the PDR for a packet of length L, p_0 is the length-independent component, and p^L is the length-dependent delivery component with p as its parameter. Note that the parameter p is roughly linked to $1 - BER$.

The introduction of a length-independent component p_0 may seem trivial, but has far-reaching consequences. For instance, if using hello packets of 50 bytes, and measuring a PDR of 50%, you cannot tell what the PDR is for 1500 bytes packets, as demonstrated by the links 5, 6, and 7, in Fig. 1. The task for the LQE suddenly involves finding two parameters instead of one. From Fig. 1, and also the other measurements in [J3], we can see that the loss in accuracy of only assuming one parameter unfortunately can be huge and this asks for improved LQE

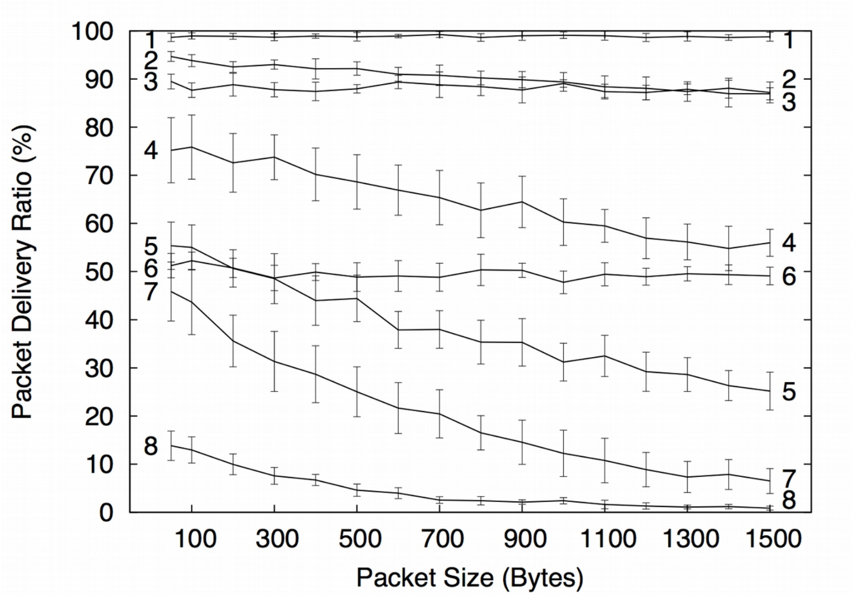

Figure 1: Packet size versus packet delivery ratio. WLAN 2 Mbps 2.4 GHz band, Indoor non-line of sight. All reported packet sizes are excluding MAC/PHY headers and postambles. The error bars show the 95% confidence interval. Every line denotes one static wireless link. For every link and packet size, 2000 packets were generated. From [J3].

methods as well as better usage of the LQE information by the higher layers. For instance, using two different hello packet sizes, such as 50 and 500 bytes.

Based on model (2), the purpose of this project is two-fold:

1. Find better LQE mechanisms that takes these new findings into account and build on model (2). These LQE mechanisms could be used in a wide range of wireless networks, such as WiFi networks, ad hoc networks, and wireless sensor networks (WSNs).
2. Investigate how higher layer protocols and mechanisms should use the extra information or be redesigned. This includes mechanisms, such as transmission power control (TPC), modulation/coding selection (MCS), packet length optimization (PLO), automatic repeat request (ARQ), routing, and other cross-layer aware mechanisms.

The methodology to be used in this project is mainly prototyping new ideas and experimental measurements. Network simulations will be used when studying the effect on larger wireless networks. Mathematical modeling and simulation will be used where applicable.

Survey of the Field

Prior to our work [J3], no systematic and comprehensive study has been done of the actual correlation between packet size and packet delivery ratio for common wireless technologies. Very few studies have been done of actual measurements. One exception is [4] that showed that the packet loss increases exponentially with the packet length and that the packet loss doubles for each additional 300 bytes on a wireless link without forward error correction (FEC) coding. Another one is [5], where the authors studied the use of hello packets in AODV routing and tried different parameter combinations. One of their conclusions is that when using hello packets of the same length as the data packets, end-to-end performance in the network increases from 60.7% to 80.8% delivery ratio.

Dong et al. [6] included one graph of one link based on IEEE 802.15.4 where packet loss for various packet sizes are shown. Also [7] looks at the packet delivery ratios for packets of different sizes and concludes a significant difference. In this case, the authors looked at the PDR difference between data packets and acknowledgements.

Link quality estimation

LQEs need to be aware of the effect that different packet sizes has, as shown in Fig. 1. Unfortunately, too many LQEs completely ignore the packet size effect and simply assume the same delivery ratio among all packet lengths. This includes even popular and recent LQEs (e.g., [2,3,8,9]).

However, a lot of work has been done in using the LQE information in higher layers, such as routing. Most of these results are still valid, but needs to be extended with the extra parameters related to the packet size.

Radio reception models

Most works concerning packet length effects are based solely on theoretical approaches [10-16]. Quite often, a Raleigh or Rician small-scale fading model is used to find the bit error rate (BER). The packet error rate (PER) is rarely discussed and when it is calculated, it is done based on (1). This means that independent bit errors are assumed and this is used without any empirical validation.

Network simulators have the same limitation [17-19]. For instance, the WiFi model in ns2 prior to version 2.33 ignores packet length effects. In version 2.33, an extended version, called WirelessPhyExt, was implemented where cumulative SINR values are calculated for every packet reception [20]. In this way, a longer packet has a somewhat higher chance of packet loss due to interference. However, without concurrent transmissions, the packet length is ignored. In [21], the authors implemented packet length effects for an older version of the original WirelessPhy code. Unfortunately, this was based on the BER model (1).

Ns3 uses different packet reception error models depending on the radio being simulated. The IEEE 802.15.4 model of Ns3 assumes the BER model (1), while the standard WiFi model, based on Yans [22,23], is quite sophisticated. However, it assumes an S-shaped curve rather than exponential decay. Hence, neither models are inline with our measurements.

Among the WSN simulators, MiXiM [24] has grown into becoming a trusted simulator. MiXiM's IEEE802154Narrow model implements packet errors based on bit error rate (BER) according to model (1) and hence ignore p_0. Castalia [25] is another WSN simulator that has an advanced modeling of the wireless channel and the radio. The standard radio reception model in Castalia 3.2 also assumes independent bit errors and essentially assume model (1).

TOSSIM [26] (from TinyOS 2.1.2) and COOJA [27] (from Contiki 2.7) are two more popular WSN simulators. However, none of them implement a packet length dependent reception model in any of their radio models. However, Dong et al. [28] report that they extended one of the radio models in TOSSIM to use the standard BER model (1) with $p_0 = 1$.

In all the simulators, there are, of course, the possibility to make small modifications to use the new model (2). This can be done for all links (e.g., one p_0 for all links) or per link (every link has their own p_0) and direction.

Packet length optimization

Packet length optimization is also sometimes referred to as *packet size adaptation*. The target in this area is to find the packet size that optimizes a criteria, such as maximizing the performance, minimizing the energy consumption, or minimizing the delay over a wireless link (e.g., [10,28,29]). Most base their work on theoretical models or simulations. Only very few of them, such as [29], did measurements, but then not of the actual impact of packet length on PER. Hence, this body of work has mainly been done without proper understanding of the effects of packet size over real wireless links.

Project Description

The aim of this project is to a) design LQE mechanisms that use model (2) and thereby better can capture the link quality, and b) better use the extra information. We have identified a small set of tasks that is needed. Below, we present them one by one. First, we present five tasks that are about creating better LQEs. Then, we present four tasks about using the new model in higher layers. The last section covers the organization and execution of the project.

Design better LQE mechanisms

1. **Using hello packets as LQE** – Many LQE methods are based on hello packets, small packets periodically emitted by every node. The frequency of losses indicate the quality of a link, but it is necessary to accumulate the reception results from many hello packets before drawing conclusions about a link's true quality. Typically, we want the hello packets to be small, since it creates less overhead and consume less power to transmit. Hence, if data packets are longer, we need to compensate for this. Can we use two different, but still small, hello packet sizes? How can we do this in a good way? Can we implement it efficiently on small WSN devices?

   Another question that arises is what happens to the accuracy if we only can use a limited number of hello packets, such as ten. This is common situation for dynamic and unstable links, where old samples quickly becomes obsolete. What happens to the prediction accuracy? What happens to hello protocol based on two different packet sizes? Numerical analysis, statistics, and simulations can be used to approach this problem.

2. **Using data packets as LQE** – Regular data or signaling packets can also be used to estimate the link quality instead of hello packets (e.g., [3]). In order to do so, it must be known which packets are lost, which can be achieved by sequence numbers, for example. Unfortunately, the lengths of the data packets are determined by the applications and they can have any length. While this can give more complete estimations, computations get more complex, in particular as the number of different packet sizes increases and we do not want to discard the usage of any data packet.

   To find p and p_0, we essentially need to do curve fitting of collected reception events. Some packet sizes may have as few as only one single such event. For instance, least-square method of the logarithms is not possible. This problem can be classified as non-linear logistic regression. However, no method is known to the PI and we also need very efficient methods, especially when frequent recalculations are required. Hence, tailored methods are needed when we base the LQE on data packets.

3. **Using coding techniques** – The reception or non-reception of a packet is what MAC and higher layer really do care about, but it is only part of the available information that can be used in an LQE. Hello packet protocols or LQE protocols based on data packets may use the information that is available also in packets received with errors. They still contain more information that can be exploited to gain extra LQE information. For

instance, the number of bit, symbol, or chip errors and their position in the packet may give valuable extra information that can be used to determine p and p_0. Forward error correction techniques or packets with known content may be used in hello packets to enable this. The research question here is how to design such mechanisms (or redesign existing LQEs, e.g., [30,31]), how much extra information can be extracted, and how to use this information in the LQE.

4. **Using signal strength, noise, and interference measurements** – From the radio and the physical layer, we also get the measurements of the received signal strength (RSS), noise levels, and interference. What do these measurements say about p and p_0? Can they be used on their own? Or combined with the above information? The research question is mainly how the signal strength, noise level, interference relate to p and p_0. And then how to redesign the existing LQEs based on this information (see [1]) to better account for the packet size effects.
5. **Other channel types** – Until now, only wide-band radio technologies have been measured and found to behave according to model (2). However, how would radically different channels behave? Would they also behave according to model (2)? In this task, we would measure other wireless communication techniques, such as ultra-wide band radios, visible light communication (VLC), and/or acoustic channels, depending on what is available and doable.

Better use of packet size-aware LQE information

1. **Packet length optimization revisited** – With the new insights of model (2) and how real wireless links behave, there is a need to revisit the packet length optimization research [6,10,15,29] and improve the results. We will look at how to find the packet length that maximizes throughput, minimizes delay, or maximizes energy-efficiency. And update the existing protocols and mechanisms when needed.
2. **Transmission power control, modulation/coding selection, and ARQ** – Besides packet length optimization, other mechanisms may benefit from the better model, such as transmission power control (TPC), modulation and coding selection (MCS), and automatic repeat request (ARQ). How are the existing protocols impacted? How can they be improved? Do we need new designs?
3. **Routing** – That routing in ad hoc or wireless sensor networks (WSN) will be impacted is clear from the results of [5], but how to do this right? The best path between two nodes may differ depending on the used packet lengths of the data packets and how to deal with this is non-trivial. Options include finding the best middle-way or to re-packetize the data so that the best packet size is used for a given path. Further, the impact on flooding protocols (e.g., [J4-J6]) should be investigated and how to further improve the flooding performance or robustness if possible.
4. **Cross-Layer usage** – The information about how different packet sizes affect the loss is also valuable at even higher layers. The research questions here is what can be gained and how to do that given accurate values of the parameters p and p_0 of model (2) in areas, such as adaptive video coding or automatic deployment of in-network processing code. Data packetizing can be changed in adaptive video coding based on p and p_0. Computational tasks to be executed inside a network (e.g. a WSN) can be moved from one node to another [J7] based on topology information that includes p and p_0 for all links.

Project plan, execution, and organization

The project will have one PhD student that will participate in the project from beginning to end where the plan is that he/she will receive a PhD degree within one year after the project end. The PI will act as the main supervisor and will spend 50% of the time on the project, both supervising and conducting research. The majority of the work will be carried out at the premises of the PI's research group at Uppsala University. Trips to conferences and shorter exchange stays at other universities will be done.

The time plan is four years and the work will roughly be conducted in the two parallel tracks outlined above. The tasks within the two tracks will mainly be conducted in the order outlined in this project description. The work will be done together by both the PI and PhD student, but also split depending on the skills and interests of the PhD student.

Research Methodology

The main work in this project will be to use empirical measurements of realistic scenarios, similar to what has been done in [J3]. This work is really about finding the actual behavior of real systems and design protocols that deal with those. Hence, it is important to continue to test new designs in realistic scenarios with real hardware in typical scenarios.

For a deeper understanding of what is happening, it is also important to carry out some measurements in controlled environments. This will involve using anechoic chambers and nodes hooked up with cables and RF attenuators.

For the work on routing, measurements in real networks can be difficult. Especially regarding scalability and reproducibility. It is also hard to analyze exactly what happens in such networks. Hence, simulations will be an invaluable option. We will work with existing discrete event network simulators, such as ns3, MiXiM, Castalia, and/or COOJA. However, we will need to update their models to include the effects that we found regarding packet sizes. In some simulators, we can update the radio packet reception models, while in others, an error model at the receiver may be more appropriate.

One alternative to synthetic models is to record packet loss data from real networks, create a trace file, and use that in the simulator (e.g., [32,33]), a technique known as *trace-based simulation*. The traces can be used in a simulator to answer questions such as which protocol is best (e.g., [32,33] or which parameters should be selected and gives more realistic results than simulations purely based on synthetic models. We believe this will be an important tool in testing various schemes as it allows rapid testing of multiple parameters and schemes, exact fairness between alternatives, and better simulation results.

Mathematical analysis and mathematical simulation will also be used where applicable. This includes curve fitting and non-linear logistic regression based on model (2), but also numerical analysis and probability theory.

Significance

The following benefits can be foreseen with this work, if successful:

- Better understanding of the effects of packet size on packet loss and how it affects higher layers.
- Better LQE schemes that accounts for packet size in an accurate way.
- Better design and usage of the packet size information in mechanisms, such as packet length optimization, ARQ, MCS, TPC, and routing.

The results will be in the form of published papers, new or modified protocol designs, simulation and measurement results, and real implementations on off-the-shelf products. Open source code contributions to simulators and common protocol stacks are expected.

Preliminary Results

This project borrows from recent results of the PI. In particular, the project will start based on the studies reported in [J3], where the PI has been investigating the packet length effect on packet delivery ratios. From the results, it is clear that packet length can have major impact on the packet delivery ratio (i.e., the LQE) and needs to be considered in any LQE mechanism. This effect depends on the link, technology, and environment.

The work of [J3] is currently being extended to look at how hello packet-based LQE protocols can be enhanced and how to use data packets (correctly received or not) to determine a link's quality.

The project will also draw from earlier work of the PI, such as [J6], where the PI shows the benefit of using trace-based simulations, and [J8], where an analytical model was proposed for the energy consumption of wireless networks.

Equipment

The research in this project will consist of experimental research and prototyping. Network state information need to be collected from actual WSN testbeds and deployments. To some degree we will be able to use open testbeds (e.g., Twist, Kansei, Indriya), but we will undoubtedly need to have our own that can be deployed in multiple locations.

Real off-the-shelf hardware is needed, such as Bluetooth and WiFi dongles, WSN nodes, and more experimental hardware for acoustics and visible light communications. For network testing, we would need about 20 nodes. Most of this equipment is not expensive, but a total cost for this is estimated to 75,000 SEK. The research group, where this research will take place, has equipment available that can be used for further experiments in this project.

Some of the measurements need to take place in a controlled environment. To do this, we will sometimes make use of the anechoic chamber that Uppsala University has. For this project, the usage cost is estimated to 10,000 SEK per year.

Independent Line of Research

This project will be led by the PI and is based on an idea and initiative of the PI. It will enable the PI to continue this very promising line of research and expand it with one PhD student. The project will help the PI to take his own research idea and make it into a full research project.

Employment

Both the PI and the PhD candidate will be employed by Uppsala University during the project. The PI is currently employed by Uppsala University.

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[15] Y. Sankarasubramaniam, I. F. Akyildiz, S. W. McLaughlin, “Energy efficiency based packet size optimization in wireless sensor networks”, in In the First IEEE International Workshop on Sensor Network Protocols and Applications (SNPA’03), Anchorage (AK), USA, May 11, 2003.

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framework", In the 15th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM'12), Paphos, Cyprus, Oct. 21-25, 2012.

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[22] M. Lacage, T. R. Henderson, "Yet another network simulator", In the 2006 Workshop on Ns-2: The IP Network Simulator, Pisa, Italy, 2006.

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[24] A. Köpke, M. Swigulski, K. Wessel, D. Willkomm, P. K. Haneveld, T. Parker, O. Visser, H. S. Lichte, S. Valentin, "Simulating wireless and mobile networks in OMNeT++: The MiXiM vision", In the 1st International Workshop on OMNeT++, Marseille, France, Mar. 2008.

[25] A. Boulis, "Castalia: Revealing pitfalls in designing distributed algorithms in WSN", In the 5th International Conference on Embedded Networked Sensor System (SenSys'07), Sydney, Australia, Nov. 6-9, 2007.

[26] P. Levis, N. Lee, M. Welsh, D. Culler, "TOSSIM: accurate and scalable simulation of entire TinyOS applications", In the 1st International Conference on Embedded Networked Sensor Systems (SenSys'03), Los Angeles (CA), USA, Nov. 5-7, 2003.

[27] F. Österlind, A. Dunkels, J. Eriksson, N. Finne, T. Voigt, "Cross-level sensor network simulation with COOJA", In the 31st IEEE Conference on Local Computer Networks (LCN'06), Tampa (FL), USA, Nov. 14-16, 2006.

[28] W. Dong, X. Liu, C. Chen, Y. He, G. Chen, Y. Liu, J. Bu, "DPLC: Dynamic packet length control in wireless sensor networks", in IEEE Conference on Computer Communications (INFOCOM'10), San Diego (CA), USA, Mar. 15-19, 2010.

[29] P. Lettieri, M. B. Srivastava, "Adaptive frame length control for improving wireless link throughput, range, and energy efficiency", in Seventeenth Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM'98), San Francisco (CA), USA, Mar. 29 – Apr. 2, 1998.

[30] M. Spuhler, V. Lenders, D. Giustiniano, "BLITZ: Wireless link quality estimation in the dark", in the European Conference on Wireless Sensor Networks (EWSN'13), Ghent, Belgium, Feb. 13-15, 2013.

[31] P. Heinzer, V. Lenders, F. Legendre, "Fast and accurate packet delivery estimation based on DSSS chip errors", In the 31st Annual IEEE International Conference on Computer Communications (INFOCOM'12), Orlando (FL), USA, Mar. 2012.

[32] A. Marchiori, L. Guo, J. Thomas, Q. Han, "Realistic performance analysis of WSN protocols through trace based simulation", In the 7th ACM Workshop on Performance Evaluation of Wireless Ad Hoc, Sensor, and Ubiquitous Networks (PE-WASUN'10), Bodrum, Turkey, Oct. 17-21, 2010.

[33] G.P. Halkes, K.G. Langendoen, "Experimental evaluation of simulation abstractions for wireless sensor network MAC protocols", EURASIP Journal on Wireless Communications and Networking, May 2010.

The applicants publications:

[J1] J. Zhou, M. Jacobsson, E. Onur, I. Niemegeers, “A novel link quality assessment method for mobile multi-rate multi-hop wireless networks”, in the 6th Annual IEEE Consumer Communications & Networking Conference (CCNC’09), Las Vegas, Nevada, USA, Jan. 10-13, 2009.

[J2] J. Zhou, M. Jacobsson, E. Onur, I. Niemegeers, “An investigation of link quality assessment for mobile multi-hop and multi-rate wireless networks”, Springer Wireless Personal Communications, vol. 65, no. 2, pp. 405 – 423, 2012.

[J3] M. Jacobsson, C. Rohner, “Estimating packet delivery ratio for arbitrary packet sizes over wireless links”, IEEE Communications Letters, In Press. [online] Available: http://dx.doi.org/10.1109/LCOMM.2015.2398443

[J4] M. Jacobsson, C. Guo, I.G.M.M. Niemegeers, “A flooding protocol for MANETs with self-pruning and prioritized retransmissions”, In the International Workshop on Localized Communication and Topology Protocols for Ad hoc Networks (LOCAN), Washington (DC), USA, Nov. 7-10, 2005.

[J5] M. Jacobsson, C. Guo, I.G.M.M. Niemegeers, “An experimental investigation of optimized flooding protocols using a wireless sensor network testbed”, Elsevier Computer Networks (ComNet), vol. 55, no. 13, pp. 2899–2913, Sep. 15, 2011.

[J6] M. Jacobsson, C. Rohner, “Comparing wireless flooding protocols using trace-based simulations”, EURASIP Journal on Wireless Communications and Networking, Article ID: 2013:169, Springer, Jun. 19, 2013.

[J7] A. Elsts, F. Hassani Bijarbooneh, M. Jacobsson, K. Sagonas, “Demo abstract: ProFuN TG: A tool using abstract task graphs to facilitate the development, deployment and maintenance of wireless sensor network applications”, in the 12th European Conference on Wireless Sensor Networks (EWSN'15), Porto, Portugal, Feb. 9-11, 2015.

[J8] J. Vazifehdan, R. Venkatesha Prasad, M. Jacobsson, I.G.M.M. Niemegeers, “An analytical energy consumption model for packet transfer over wireless links”, IEEE Communications Letters, vol. 16, no. 1, Jan. 2012.

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project*

	Role in the project	Name	Percent of full time
1	PhD Student		80
2	Applicant	Martin Jacobsson	50

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	2019	Total
1	Applicant	Martin Jacobsson	50	374,000	384,000	393,000	403,000	1,554,000
2	PhD Student	Doktorand 1	80	395,000	401,000	424,000	447,000	1,667,000
	Total			769,000	785,000	817,000	850,000	3,221,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	2019	Total
1	Arbetsrum	40,000	40,000	40,000	40,000	160,000
	Total	40,000	40,000	40,000	40,000	160,000

Running Costs

	Running Cost	Description	2016	2017	2018	2019	Total
1	Resor		45,000	45,000	45,000	45,000	180,000
2	Kontorsutrustning		22,500	7,500	7,500	7,500	45,000
3	Projektutrustning		50,000	25,000			75,000
4	Anekoisk kammare		10,000	10,000	10,000	10,000	40,000
	Total		127,500	87,500	62,500	62,500	340,000

Depreciation costs

Depreciation cost	Description	2016	2017	2018	2019

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	2019	Total, applied	Other costs	Total cost
Salaries including social fees	769,000	785,000	817,000	850,000	3,221,000		3,221,000
Running costs	127,500	87,500	62,500	62,500	340,000		340,000
Depreciation costs					0		0
Premises	40,000	40,000	40,000	40,000	160,000		160,000
Subtotal	936,500	912,500	919,500	952,500	3,721,000	0	3,721,000
Indirect costs	254,000	254,000	264,000	274,000	1,046,000		1,046,000
Total project cost	1,190,500	1,166,500	1,183,500	1,226,500	4,767,000	0	4,767,000

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Salary Applicant / Project Leader

The work will in part be carried out by the main applicant. This also includes supervising the PhD student of this project. The main applicant will spend 50% of his time on the project.

Salary PhD Student

The plan is to have one PhD student on the project and to do a large part of the work. In our department, PhD students spend 20% teaching, the remaining 80% will be spent on this project.

Office Computers, etc (Kontorsutrustning)

Costs for basic office equipment, including laptops and desktop computers.

Premises (Arbetsrum)

Cost related to office space for both the main applicant (50%) and the PhD student (80%).

Travel (Resor)

Typical travel costs for presenting at conferences and other publication fees for both project participants. This cost also includes article processing charges for submissions to open access journals and similar.

Anechoic chamber (Anekoisk kammare)

Costs for using the anechoic chamber of Uppsala University, which is used for controlled experiments of radio communications.

Project-related Equipment (Projektutrustning)

This post is used to buy additional special hardware required for the project. See the research plan, section "Equipment" for more details.

Some minor equipment that the Communication Research (CoRe) group at Uppsala University already have, will be borrowed by the project.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	2019

CV and publications

CV

Curriculum Vitae – Dr. Martin Jacobsson

Box 337, 751 05 Uppsala, Sweden
martin.jacobsson@it.uu.se, +46 70 425 02 68, http://www.jacobsson.nl/research

1. Higher education degree

M.Sc./B.Sc. Program in Computer Science, August 2001, *Linköping University*, Sweden

Final thesis work at Ericsson ELN in Enschede, The Netherlands. Supervised by Prof. Ignas G.M.M. Niemegeers (University of Twente, The Netherlands, at the time) and Dr. Georgios Karagiannis (Ericsson, The Netherlands, at the time). Title: "Resource Management in Differentiated Services – A Prototype Implementation". Thesis graded 10 out of 10, which is extremely exceptional in the Dutch grading system.

2. Doctoral degree

Date of defense:	June 17, 2008
University:	Delft University of Technology, The Netherlands Department of Telecommunications, Wireless and Mobile Communications Group (WMC)
Area:	Telecommunications, Electrical Engineering
Doctoral advisor:	Prof.dr.ir. Ignas G.M.M. Niemegeers
Title:	Personal Networks – An Architecture for Self-Organized Personal Wireless Communications

3. Postdoctoral positions

Jul 2008 – Jul 2011, Post-Doctoral Researcher at *Delft University of Technology*, The Netherlands

Department of Telecommunications, Wireless and Mobile Communications Group (WMC)

I spent three weeks at University of California, Irvine together with Prof. Magda el Zarki in February/March 2009. Also visited Prof. Gene Tsudik and Prof. Ramesh Jain.

4. Docent level

5. Current position

Dec 2011 – Present, Post-Doctoral Research Fellow at *Uppsala University*, Sweden

Communication research group, Department of information technology. 80% research, 20% teaching

Currently partly working with a SSF-funded research project called ProFuN that is investigating how to make it easier for developers to program wireless sensor networks (WSN). Involved in teaching as course responsible for the introduction course in IT for our freshmen CS and IT students as well as the course Computer Networks II (an advanced level course).

6. Previous positions and periods of appointment

Sep 2001 – Dec 2002, Software Engineer at *Philips Business Communications*, Hilversum, The Netherlands

7. Deductible time

8. Supervision

Main supervisor for:

- Charalampos Orfanidis. Tentative Title: SDN Architectures for Internet of Things. Expected defense in 2020.

I acted as co-supervisor for:

- Dr. Jinglong Zhou, October 26, 2010. Title: Impact of Wireless Link Quality across Communication Layers

Also supervised or co-supervised 11 students in their master thesis work (8 at TU Delft, 3 at Uppsala University).

9. Other information

Participated in three European FP6 research projects: IST NEXWAY (Network of excellence), IST MAGNET (Integrated project), and FFL12-0193 Jacobsson, Martin Reliable global networked sensors and actuators IST MAGNET Beyond (Integrated project) and two Dutch research projects: Freeband PNP2008 (with Philips, KPN, TNO ICT, University of Twente). Connect Your World of Devices (STW Valorisation Grant Phase 1)

Through these projects, I have been able to significantly widen my academic and industrial network across Europe, especially MAGNET, which lasted for 4.5 years and consisted of 30 partners from all corners of Europe. In PNP2008, we worked together with Dutch universities (Delft and Twente), research institutes (TNO ICT), and industry (Philips, KPN, TI-WMC).

Was task leader in a European FP6 IP project for the tasks related to service control and interworking (~15 researchers from 7 partner organizations). Was work package leader for the technical scientific work package (~10 researchers from 5 partner organizations) in the last year of a Dutch research project.

Was also involved in the defining of several project proposals for FP6 and FP7 calls and other European (Celtic), Dutch (STW), Swedish (VR, Vinnova, Formas) funding agencies as well as one NSF project proposal (on behalf of University of California Irvine).

A key workshop organizer in all five International Workshops on Personalized Networks (Pernets), which were organized in conjunction with Mobiquitous and then IEEE CCNC. Also involved in reviewing and on the TPC. TPC co-chair for the sixth Pernets workshop. TPC co-chair in E2Nets'13 and E2Nets'14 cohosted with IEEE ICC. TPC Co-chair in the workshop of Next Generation Green ICT to be held at IEEE ICC 2015 in London.

Reviewer for many international workshops, conferences, and journals, including Springer Wireless Personal Communications, Springer Wireless Networks, EURASIP Journal on Wireless Communications and Networking, IEEE Communications Letters, IEEE Transactions on Wireless Communication, European Transactions on Telecommunications, Pernets, E2Nets, PWC, PIMRC, GLOBECOM, ICC, SECON, and many more.

Best student paper award at IEEE CCNC 2009 in Las Vegas, USA.

Gave a half-day tutorial on Personal Networks at the IEEE CCNC conference in Las Vegas, USA in January 2011. Gave a full-day version for the European Patent Office in The Hague in May 2011.

h-Index (Google Scholar): 14

Publication list

Publication List – Dr. Martin Jacobsson

Publication list from April 2007. The five publications most relevant to the project are marked with an asterisk (*).

Peer-reviewed articles

1. Anthony Lo, Weidong Lu, Martin Jacobsson, Venkatesha Prasad, Ignas G.M.M. Niemegeers, Personal Networks – An Architecture for 4G Mobile Communications Networks, *Telektronikk*, Issue: 1.07, Pages: 45–58, Telenor, April 2007.
2. Novi I. CempakaWangi, R. Venkatesha Prasad, Martin Jacobsson, Ignas G.M.M. Niemegeers, Address Autoconfiguration in Wireless Ad Hoc Networks: Protocols and Techniques, *IEEE Wireless Communications Magazine*, Volume: 15, Issue: 1, February 2008.
3. Xiaoming Zhou, Martin Jacobsson, Henk Uijterwaal, Piet F.A. van Mieghem, IPv6 Delay and Loss Performance Evolution, *International Journal of Communication Systems*, Volume 21, Issue 6, Pages 643–663, June 2008.
4. Jinglong Zhou, Martin Jacobsson, Ignas Niemegeers, "Link Quality-Based Transmission Power Adaptation for Reduction of Energy Consumption and Interference", *EURASIP Journal on Wireless Communications and Networking*, Volume 2010 (2010), Article ID 920131, December 2010.
5. Martin Jacobsson, Cheng Guo, Ignas Niemegeers, An Experimental Investigation of Optimized Flooding Protocols using a Wireless Sensor Network Testbed, *Elsevier Computer Networks (ComNet), Elsevier Computer Networks (ComNet)*, Volume 55, Issue 13, Pages 2899–2913, September 15, 2011.
6. Cheng Guo, R. Venkatesha Prasad, Jiang Jie He, Martin Jacobsson, Ignas Niemegeers, Designing a flexible and low-cost testbed for Wireless Sensor Networks, *Inderscience International Journal of Ad Hoc and Ubiquitous Computing (IJAHUC)*, Volume 9, Issue 2, Pages 111-121, 2012.
7. * Javad Vazifehdan, R. Venkatesha Prasad, Martin Jacobsson, Ignas Niemegeers, An Analytical Energy Consumption Model for Packet Transfer over Wireless Links, *IEEE Communications Letters*, Volume 16, Issue 1, January 2012.
8. * Jinglong Zhou, Martin Jacobsson, Ertan Onur, Ignas Niemegeers, An Investigation of Link Quality Assessment for Mobile Multi-hop and Multi-rate Wireless Networks, *Springer Wireless Personal Communications*, Volume 65, Number 2, Pages 405-423, July 2012.
9. * Martin Jacobsson, Christian Rohner, Comparing Wireless Flooding Protocols using Trace-based Simulations, *EURASIP Journal on Wireless Communications and Networking*, Article ID: 2013:169, Springer, June 19, 2013.
10. Anthony Lo, Yee Wei Law, Martin Jacobsson, A Cellular-Centric Service Architecture for Machine-to-Machine (M2M) Communications, *IEEE Wireless Communications Magazine*, Volume 20, Issue 5, Pages 143-151, October 2013.
11. * Martin Jacobsson, Christian Rohner, Estimating Packet Delivery Ratio for Arbitrary Packet Sizes over Wireless Links, *IEEE Communications Letters*, In Press. [online] Available: http://dx.doi.org/10.1109/LCOMM.2015.2398443

Peer-reviewed conference contributions

(There are 15 peer-reviewed conference contributions before April 2007.)

1. Jinglong Zhou, Martin Jacobsson, Ignas G.M.M. Niemegeers, Cross Layer Design for Enhanced Quality Personal Wireless Networking, In *the Sixth Annual Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net'07)*, Corfu, Greece, June 13-15, 2007.
2. Jinglong Zhou, Martin Jacobsson, Ignas Niemegeers, Cross Layer Design for Enhanced Quality Routing in Personal Wireless, In *the Second International Workshop on Personalized Networks (Pernets'07)*, Philadelphia (PA), USA, August 10, 2007.
3. Jinglong Zhou, Martin Jacobsson, Ertan Onur, Ignas G.M.M. Niemegeers, Factors that Impact Link Quality Estimation in Personal Networks, In *the 8th International Symposium On Computer Networks (ISCN'08)*, Istanbul, Turkey, June 18-20, 2008.
4. R. Venkatesha Prasad, Yonghua Li, Martin Jacobsson, Anthony Lo, Ignas G.M.M. Niemegeers, FEW-PNets – A Framework for Emulations of Wireless Personal Networks, In *the IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WOWMOM'08)*, Newport Beach (CA), USA, June 23-27, 2008.
5. Ertan Onur, Martin Jacobsson, Sonia M. Heemstra de Groot, Ignas G.M.M. Niemegeers, Manageable Bubbles of the Future Internet: Personal Super Virtual Devices, In *the 21st Wireless World Research Forum (WWRF) Meeting*, Stockholm, Sweden, October 13-15, 2008.
6. * Jinglong Zhou, Martin Jacobsson, Ertan Onur, Ignas Niemegeers, A Novel Link Quality Assessment Method for Mobile Multi-Rate Multi-Hop Wireless Networks, In *the 6th Annual IEEE Consumer Communications & Networking Conference (CCNC'09)*, Las Vegas, Nevada, USA, January 10-13, 2009. (**Best Student Paper Award**)
7. Cheng Guo, Jing Wang, Martin Jacobsson and R. Venkatesha Prasad, An experimental investigation of improving the accuracy of Person Localization with Body Area Sensor Networks, In *the Third International Workshop on Personalized Networks (Pernets'09)*, Las Vegas, Nevada, USA, January 13, 2009.
8. Javad Vazifehdan, Martin Jacobsson, Ignas G.M.M. Niemegeers, A Generic Framework for Gateway and Access Network Selection in Personal Networks, In *the Third International Workshop on Personalized Networks (Pernets'09)*, Las Vegas, Nevada, USA, January 13, 2009.
9. Jinglong Zhou, Ertan Onur, Martin Jacobsson, Ignas Niemegeers, On the smoothing factor for rate adaption in ieee 802.11b/g mobile multi-hop networks, (In Turkish), In *the 17th IEEE Conference on Signal Processing and Communications Applications (SIU'09)*, Antalya, Turkey, April 9-11, 2009.
10. Jinglong Zhou, Xin Zhang, Martin Jacobsson, Ignas Niemegeers, Link Quality-based Transmission Power Adaptation for Energy Saving in IEEE 802.11, In *the 20th Personal, Indoor and Mobile Radio Communications Symposium (PIMRC'09)*, Tokyo, Japan, September 13-16, 2009.
11. Cheng Guo, R. Venkatesha Prasad, JiangJie He, Martin Jacobsson, FIST: A Framework for Flexible and Low-cost Wireless Testbed for Sensor Networks, In *the 2009 International Conference on Future Generation Communication and Networking (FGCN'09)*, Jeju Island, Korea, December 10-12, 2009.

12. Cheng Guo, R Venkatesha Prasad, and Martin Jacobsson, Packet Forwarding with Minimum Energy Consumption in Body Area Sensor Networks, In *the Fourth IEEE International Workshop on Personalized Networks (Pernets'10)*, Las Vegas, Nevada, USA, January 9, 2010.
13. Cheng Guo, Martin Jacobsson, R. Venkatesha Prasad, A Case Study of Networked Sensors by Simulations and Experiments, In *the 2010 International Conference on Thermal, Mechanical and Multiphysics Simulation and Experiments in Micro/Nanoelectronics and Systems (EuroSimE'10)*, Bordeaux, France, April 26-28, 2010.
14. Anthony Lo, Yee Wei Law, Martin Jacobsson, Enhanced LTE-Advanced Random-Access Mechanism for Massive Machine-to-Machine (M2M) Communications, In *the 27th World Wireless Research Forum (WWRF) Meeting*, Düsseldorf, Germany, October 18-20, 2011.
15. Farshid Hassani Bijarbooneh, Martin Jacobsson, Macroprogramming of Wireless Sensor Networks using Task Graphs and Constraint Solving, In *the 8th Swedish National Computer Networking Workshop (SNCNW'12)*, Stockholm, Sweden, June 7-8, 2012.
16. Atis Elsts, Farshid Hassani Bijarbooneh, Martin Jacobsson, Konstantinos Sagonas, Demo Abstract: ProFuN TG: A Tool Using Abstract Task Graphs to Facilitate the Development, Deployment and Maintenance of Wireless Sensor Network Applications, in the *12th European Conference on Wireless Sensor Networks (EWSN'15)*, Porto, Portugal, February 9-11, 2015.

Review articles, book chapters, books

1. Martin Jacobsson, Ignas Niemegeers, Sonia Heemstra de Groot. *Personal Networks – Wireless Networking for Personal Devices*, ISBN 978-0-470-68173-2, John Wiley & Sons, Chichester, June 2010.

Patents

1. Georgios Karagiannis, Simon Oosthoek, Martin Jacobsson (co-inventors), "Maintenance of Sliding Window Aggregated State using Combination of Soft and Explicit Release Principles", Pub. No.: WO/2002/076035, Telefonaktiebolaget LM Ericsson, September 26, 2002.

Popular science articles/presentations, other

1. Ecma International, Personal Networks – Overview and Standardization Needs, Technical Report TR/102, December 2010.
2. Connect All Your Electronic Devices with Personal Networks – Architectures, Technologies, Applications (Half Day), IEEE Consumer Communications and Networking Conference (CCNC'11), Las Vegas, USA, January 12, 2011.

Open access computer programs

1. ProFuN TG. Part of the code is mine. Available online: http://parapluu.github.io/profun/

CV

Name: Martin Jakobsson	**Doctorial degree:** 2008-06-17
Birthdate: 19760306	**Academic title:** Doktor
Gender: Male	**Employer:** Uppsala universitet

Research education

Dissertation title (swe)

Dissertation title (en)

Personal Networks – An Architecture for Self-Organized Personal Wireless Communications

Organisation	Unit	Supervisor
TU Delft, Netherlands Not Sweden - Higher Education institutes	EWI	Ignas Niemegeers

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20203. Kommunikationssystem	978-0-470-68173-2	2008-06-17

Publications

Name: Martin Jakobsson	**Doctorial degree:** 2008-06-17
Birthdate: 19760306	**Academic title:** Doktor
Gender: Male	**Employer:** Uppsala universitet

Jakobsson, Martin has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.